



Full Scale Test SSP 34m blade, edgewise loading LTT. Extreme load and PoC_InvE Data report

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Full Scale Test SSP 34m blade, edgewise loading LTT. Extreme load and PoC_InvE Data report

Risø-R-Report

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Title: Full Scale Test SSP 34m blade, edgewise loading LTT. Extreme load and PoC_InvE Data report
Division: Wind Energy Division

Abstract :

This report is the second report covering the research and demonstration project “Eksperimentel vingeforskning: Strukturelle mekanismer i nutidens og fremtidens store vinger under kombineret last”, supported by the EUDP program. A 34m wind turbine blade from SSP-Technology A/S has been tested in edgewise direction (LTT). The blade has been submitted to thorough examination by means of strain gauges, displacement transducers and a 3D optical measuring system. This data report presents results obtained during full scale testing of the blade up to 80% Risø load, where 80% Risø load corresponds to 100% certification load. These pulls at 80% Risø load were repeated and the results from these pulls were compared.

The blade was reinforced according to a Risø DTU invention, where the trailing edge panels are coupled. The coupling is implemented to prevent the out of plane deformations and to reduce peeling stresses in the adhesive joints. Test results from measurements with the reinforcement have been compared to results without the coupling.

The report presents only the relevant results for the 80% Risø load and the results applicable for the investigation of the influence of the invention on the profile deformation.

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Contents

Terms and Definitions.....	1
1. Introduction	3
2. Experimental Procedure	4
2.1 Loading.....	4
2.2 Measurements.....	5
3. Results.....	7
3.1 Strain Gauge Measurement at the Adhesive Joint.....	8
3.2 Flapwise Deflection.....	11
3.3 Strain Measurements at the Middle of the Trailing Edge Panels.....	13
4. Structural Solution under Investigation.....	14
4.1 The Patent / The invention.....	14
4.2 Measurements for Prove of Concept	15
5. Results With and Without Reinforcement	17
5.1 Overview of the Deformation.....	17
5.2 Strain Result Study	18
5.3 Influence of the Reinforcement on the Shear Distortion	22
6. Digital Image Correlation (DIC) and FEM results.....	25
6.1 DIC Comparison With and Without Reinforcement	25
6.2 Comparison between FEM Analyses and DIC	27
6.3 Behaviour of the Panels under Tension	29
7. Summary and Conclusion.....	31
8. References.....	32
9. Appendices	33

Terms and Definitions

The blade cross section with the main structural features is presented in Figure 0.1.

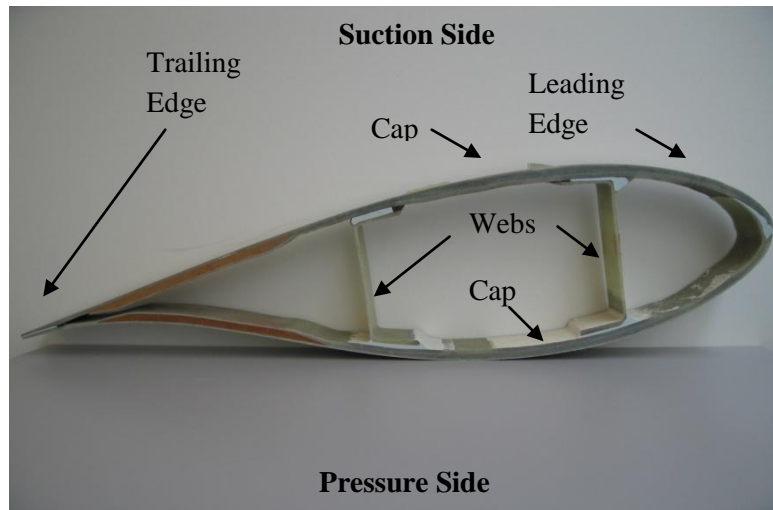


Figure 0.1. Picture of a blade cross-section indicating construction elements.

Definitions

Blade root:	Part of the wind turbine blade that is closest to the rig
Box girder:	Primary lengthwise structural member of a wind turbine blade
Edgewise:	Direction that is parallel to the local chord of the blade
Flapwise:	Direction that is perpendicular to the surface swept by the non-deformed rotor blade axis
Trailing edge (TE):	Edge of blade pointing opposite travelling direction
Leading edge (LE):	Smooth edge of blade pointing the travelling direction
FEM:	Finite Element Method
DIC:	Digital Image Correlation, 3D optical measuring system

Table 0.1. Loading directions with respect to the blade.

Load case
PTS - pressure side towards suction side
STP - suction side towards pressure side
TTL - trailing edge towards leading edge
LTT - leading edge towards trailing edge

The coordinate system

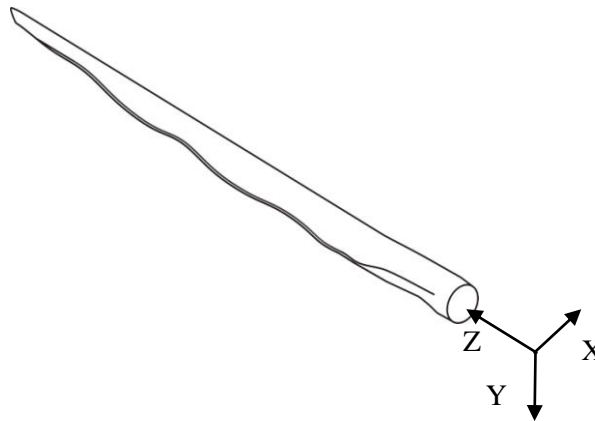


Figure 0.2. Coordinate system.

The x-axis is directed in edgewise (wind) direction, positive towards leading edge. The y-axis is in flapwise direction, positive in direction from pressure to suction side. The z-axis is along the blade, pointed from the root of the blade, as indicated in Figure 0.2.

Measurement equipment

Strain gauges (SG)

UD	Uni Directinal (0° in longitudinal direction)
Bx	Biax ($0^\circ/90^\circ$)
Tx	Triax-Rosette ($0^\circ/45^\circ/90^\circ$)
Back to back	One strain gauge on each (inner and outer) side of the blade

Linear transducers (LT)

LT-ASM	Length Transducer from ASM – Cable actuated position sensors
LT-NT	Length Transducer from NovoTechnik

Optical measurement

DIC:	Digital Image Correlation
Aramis:	3D-DIC-system from GOM (www.gom.com)

1. Introduction

This report documents measurements from tests up to 80% of extreme loads (called Risø load), where 80% extreme loads correspond to the certification load. The measurements presented in this report are the results from pulls at 80% Risø and pulls performed for prove of concept Invention E, called PoC_E, where the trailing edge panels are coupled. The coupling was implemented to prevent the out of plane deformation of the panels in order to reduce peeling stresses in the adhesive joints.

The results in this report are obtained as additional results when carrying out the EUDP project “Eksperimentel Vingeforskning. Strukturelle mekanismer i nutidens og fremtidens store vinger under kombineret last”, sponsored by the Energy Technology Development and Demonstration Program 63011-0066. Industrial partners of the project are Vestas, LM-Wind Power A/S, SSP-Technology A/S.

The edgewise load case up to 60% Risø load is presented earlier in “Data report 1” ref. [1]. This previous data report includes a comprehensive description of the load set up, measurements and data acquisition system.

The purpose of this data report is to present results obtained during full scale testing of a 34m blade in leading towards trailing edge (LTT) direction up to 80% of Risø loads. Moreover, results comparison for repeated loading is performed. Finally, the results from test with Invention E implemented are also presented.

2. Experimental Procedure

This chapter gives a short presentation of the test conditions. The test itself, its set up and preparation are described in details in the “Data report 1”, ref. [1]. The tests presented in the two data reports differ in that the load is increased to 80% of the Risø load in several tests and that a ‘maintenance hole’ in the web was reinforced. The function of this hole is to allow people to crawl between the trailing edge panels in order to instrument and reinforce them. The maintenance hole was reinforced to prepare for the future combined load test. This reinforcement is shown in Figure 2.1 and Figure 2.2.



Figure 2.1 The maintenance hole in the web.



Figure 2.2 Reinforcement of the hole.

When the tests were carried out, the blade was, as previously mentioned, loaded up to 80% Risø load. This load corresponds to the certification loads. Therefore, acoustic emission measurements were performed during the first two tests at that load in order to enable detection of crack initiation, see the results from the acoustic emission in Appendix C.

The blade has been tested with and without the reinforcement suggested in Invention E. The reinforcement between the panels can be seen in Figure 4.2 and Figure 4.3, and ref. [2].

2.1 Loading

The forces applied in the investigated load case are presented in Table 2.1. These values define the so-called Risø load, which is considered the extreme load, and is defined as the design load multiplied by 1.23. The background for this factor is experimental testing of a similar blade, which has carried such amount of load (in flapwise direction) before it failed, see ref. [3], [4].

Table 2.1. The forces applied on the blade in the investigated LTT load case.

Section of application [m from the root]	Applied force [N]
13.21	40013
18.61	31675
24.91	58099

When testing to 80% Risø load, the loads applied to blade are 0.8 of the above mentioned loads.

For LTT test, the blade is mounted on a test rig as presented in Figure 2.3. The loading system was designed specifically for this test facility and it is described in details in ref. [1].

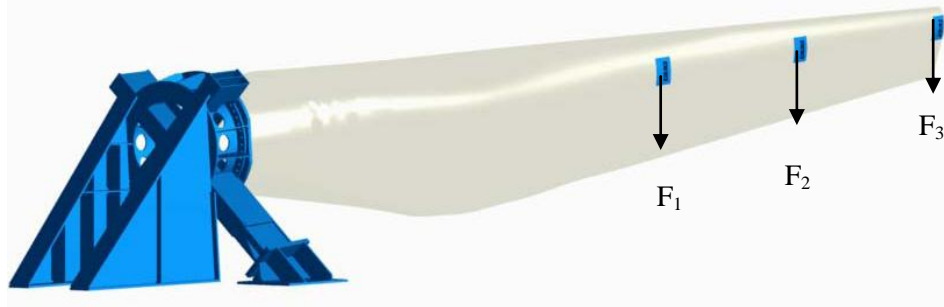


Figure 2.3. Sketch of the blade bolted to the test rig. The tip has been cut off, so only 25m is tested. The arrows indicate the pulling direction in the LTT load case.

In order to allow comparison between the current test and the previous ones, the load caused by the gravity force needed to be considered while establishing the applied load. It was decided to account for the gravity load by reducing the values of the applied load. The gravity load was represented by forces acting on the blade in the same three sections at which the test load is applied. Moreover, the truncated tip needed to be compensated for. Therefore, a preloading was applied at the tip in order to account for the forces from the missing part. The calculations and adjustments made are presented in ref. [1]. After applying the preloading and the adjustment forces, all the measuring equipment excluding the measurement of the applied forces was set to zero. Due to the gravity load (including the tip preloading) and adjustment, the measurements were started at 30% of the Risø load. A more detailed explanation and verification can be found in ref. [1].

2.2 Measurements

The experimental methods used in the tests include a large number of strain gauges and displacement sensors. Moreover, an advanced 3D optical measuring system (DIC) and acoustic emission equipment has been used. A detailed description of the data and measurements equipments as well as how the tests were performed can be found in ref. [1].

This report covers the results from pulls with 80% Risø load and for the region of interest when evaluating the coupling between the panels presented in Figure 4.2.

Figure 2.4 presents the placement of measurement equipment at the 3m section, for some important measurements when evaluating invention E. The letters are notations for specific placements at all sections of the blade. The indices to these letters refer to the side of the blade: S for suction side and P for pressure side. The strain gauges were mounted in the ‘back to back’ manner where it was practically feasible.

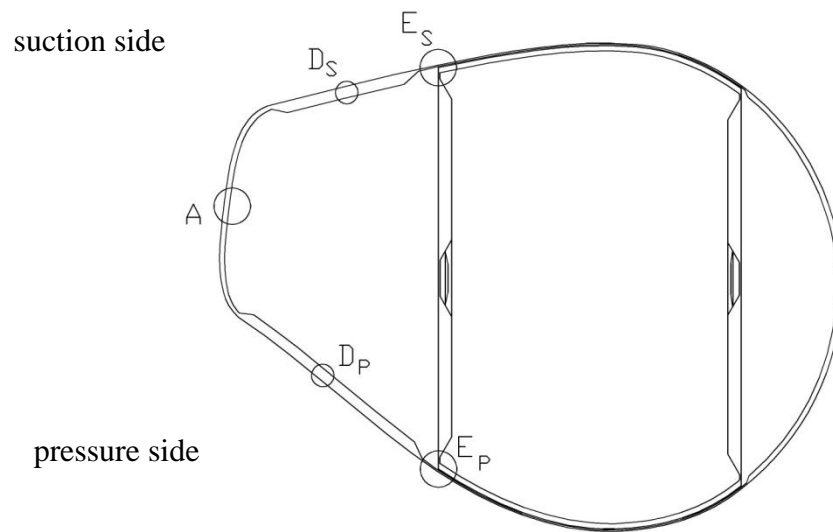


Figure 2.4. Positions of the measurement equipment crucial for the investigations presented in this report.

The direction of the strain with respect to the blade are 1 - longitudinal direction, 2 - transversal direction, as indicated in Figure 2.5.

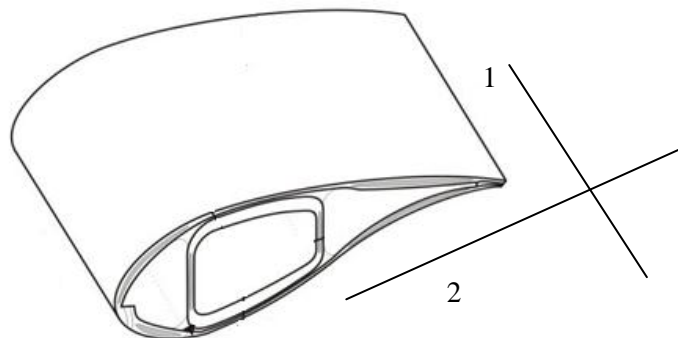


Figure 2.5. Directions of the strain measurements with respect to the blade.

For further, detailed explanation of the measurement equipment positioning see ref. [1], [3] and [4]. All the strain gauge positions for the test at 80% Risø load are listed in Appendix A and the remaining ones are presented in the first data report ref. [1].

3. Results

The pulls were performed in order to test the blade up to 80 % of Risø load, which corresponds to the certification load, and at the same time performing measurements to investigate the influence of the invention E. At 80% Risø load the data was collected by means of the measurement equipment situated in the areas where the blade was most likely to fail.

The pulls at 80% Risø load were repeated, and the study of these results revealed that the results changed when the pulls were recurrent. The pulls *ELLT_6_250610_A*, *ELLT_6_250610_B* and *ELLT_6_250610_C* were all performed at the same date. The pulls *ELLT_6_250610_B* and *ELLT_6_250610_C* were performed in order to get DIC measurements in 4 and 11m sections without the invented reinforcement implemented. The pulls *ELLT_4_131009_A* and *ELLT_6_250610_A* are performed with the reinforcement (see the description of the reinforcement in chapter 4.1). Between pull *ELLT_6_290110* and *ELLT_6_250610_A* the reinforcement of the maintenance hole in the web has been implemented, see Figure 2.1 in Section 2.

Table 3.1 presents the individual pulls and the order in which they were performed.

Table 3.1 . List of tests presented in this data report

Name of pull	Load in%	Date	Invention implemented	Center of DIC-measurements
ELLT_4_131009_A	60%	131009	yes	4m P
ELLT_1_191009_A	60%	191009	no	16m S
ELLT_6_290110	80%	290110	no	no
ELLT_6_250610_A	80%	250610 first pull	yes	4m P
ELLT_6_250610_B	80%	250610 second pull	no	4m P
ELLT_6_250610_C	80%	250610 third pull	no	11m P

This chapter describes the findings from pulls performed at 80% Risø load which is not concerning the investigation of the Invention. The findings described are:

- Strain measurement at the adhesive joint in 4.5 m in position E_p
- Global flap wise deformation in 10 m
- Strain gauge measurements at the middle of pressure side trailing edge panels

In Appendix A, a list with the measurement equipment used in the tests is presented.

3.1 Strain Gauge Measurement at the Adhesive Joint

One of the measurements which changed during repeated measurements is the longitudinal strain inside the blade in 4.5m at position E_p . These results are shown in the diagrams in this section. Figure 3.1 shows the location for these measurements.

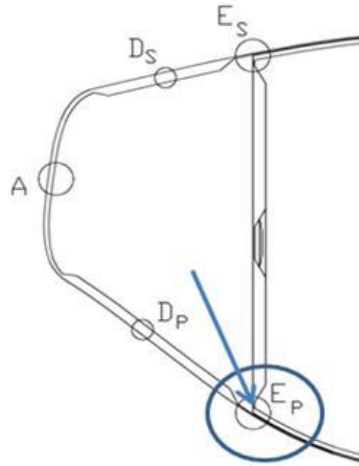
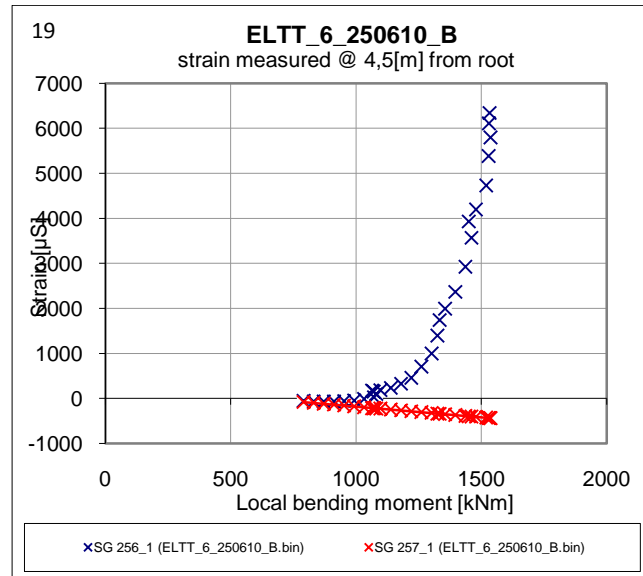
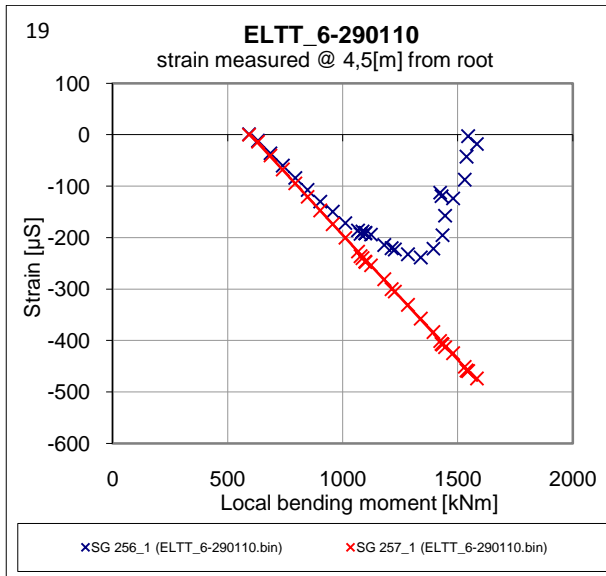


Figure 3.1. The position inside the panels showing changes during repeated pulls.

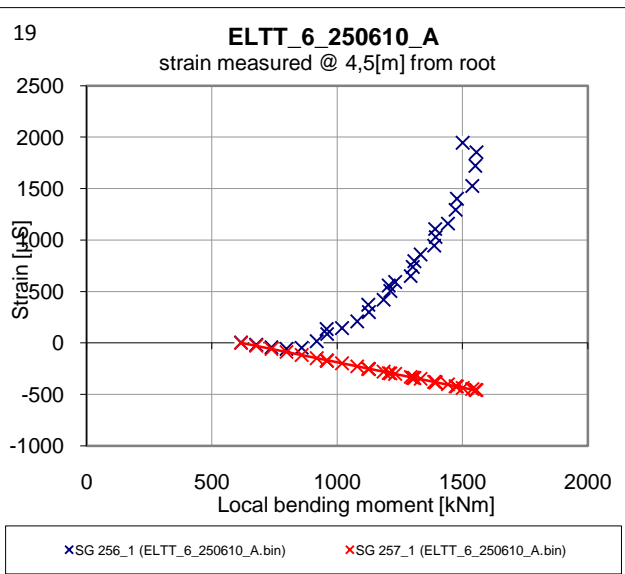
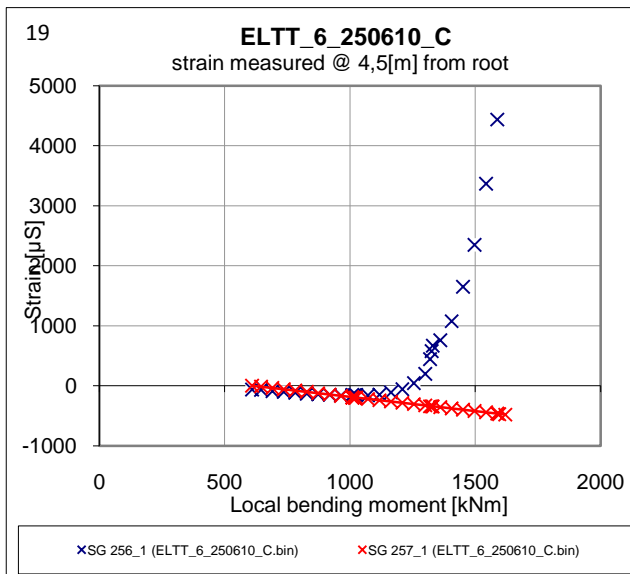
The transversal strain measurements at 4.5m inside and outside the blade at the E_p position, as described, did not show any evident changes during repeated pulls. The results from these measurements can be found in Appendix B.

The result from the longitudinal strain measurements inside the panels are shown in Figure 3.2. As described in section 2.1 and in ref. [1], strains are reset to zero at 30% Risø load, as the load is adjusted according to the gravity load of the blade. For strains being a linear function of the moment, the total strain is found by elongating the strain curve to horizontal axis.



A. First pull with 80% Risø load. This pull is performed without reinforcement of the maintenance hole and without the invented reinforcement between the panels

B. Third pull with 80% Risø load, and second pull without the invented reinforcement and also the second pull with the reinforcement of the maintenance hole.



C. Forth pull with 80% Risø load. It is the third pull without the invented reinforcement, and the third pull with the reinforcement of the maintenance hole.

D. Second pull with 80% Risø load, which is the first pull with the invented reinforcement and the first pull with the reinforcement of the maintenance hole.

Figure 3.2. Results from strain measurements in 4.5 m where the strain behaviour has changed during repeated measurements. The strain gauges presented are placed back to back and the strain gauge studied is SG_256_1.

During the first and second pull performed at 80% Risø load, the blade was monitored with acoustic emission in 4m and 11.5m. These measurements did not show any indication of damage on the blade. A failure in the blade during test was expected to be recorded, since the microphones in 4m were close to the investigated strain gauge. The acoustic emission results are given in Appendix C.

The strain gauge giving interesting measurement was placed at the glued connection between the box and the panels. This area of the blade was examined visually. Inspection of the adhesive joint between the panels and the box did not reveal any significant phenomena.

The photos in Figure 3.3 shows the strain gauge glued to the surface.

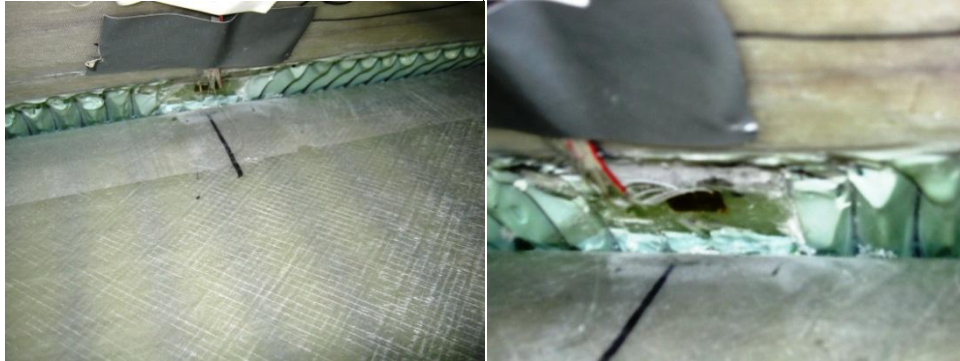


Figure 3.3 Photos of the area near to the strain gauge measurement at 4.5m.

Measurements given in previous pulls by this strain gauge, called *SG 257_1*, were examined in order to explore its history. Study of the result from pre-test and the first test revealed that this strain gauge shown peculiar behaviour from the beginning, see Figure 3.4.

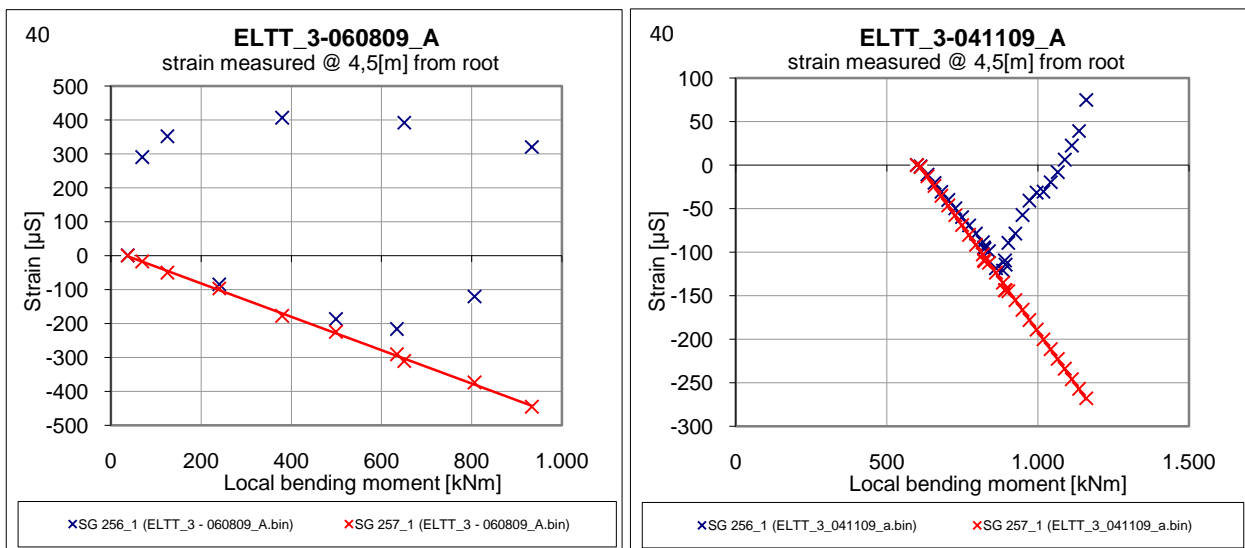


Fig. a

Fig. b

Figure 3.4 Fig. a. Result from a pre-test with *SG 257_1*. The result above presents both loading and unloading of the blade. Fig. b. Results from the first pull with measurements of *SG 257_1*.

3.2 Flapwise Deflection

During repeated pulls some interesting change in the flapwise deflection measurement occurred at 10m. The deflection was reduced during repeated load application. At the same time the deflection was more sensible to the load application procedure, and it rose abruptly when the loads were adjusted.

In Figure 3.5, measurement equipment at 10m section is shown, and measurement called ASM_100_23, ASM_100_24 and ASM_100_25 are examined. They are placed on the suction side of the blade and are connected to the wall.

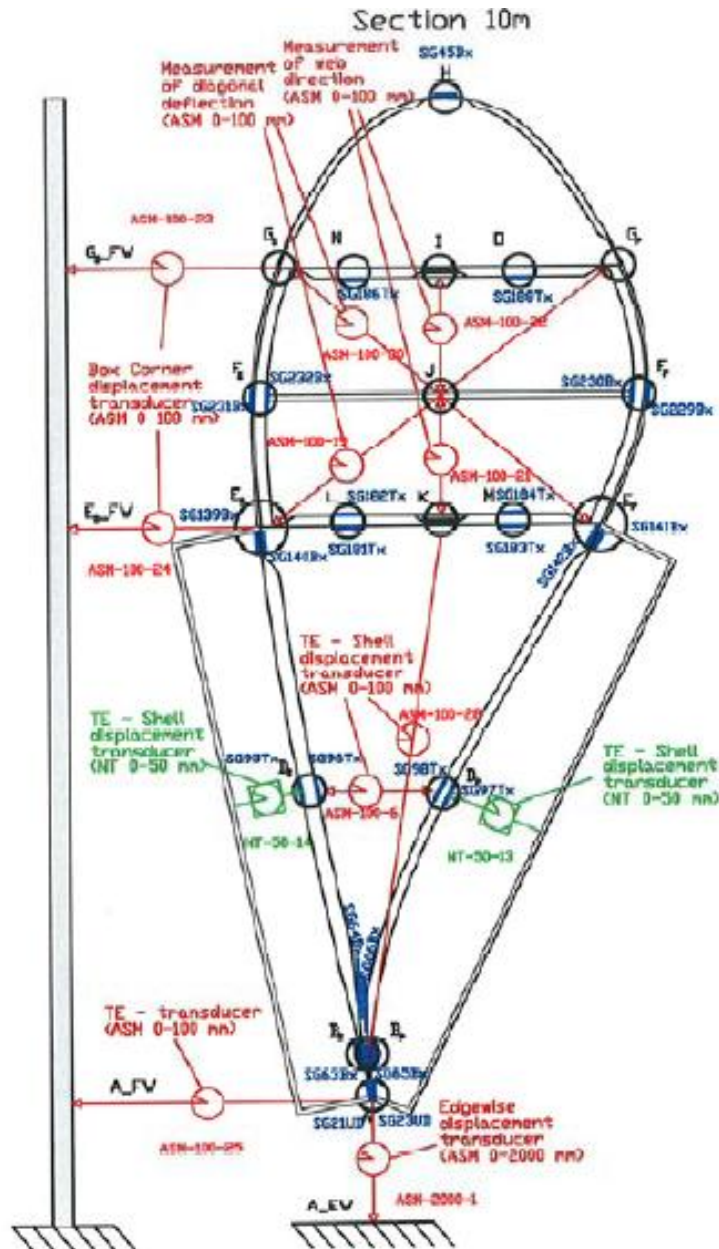


Figure 3.5. Measurement equipment at section 10m.

The results from the measurements discussed above are presented in Figure 3.6 to Figure 3.8.

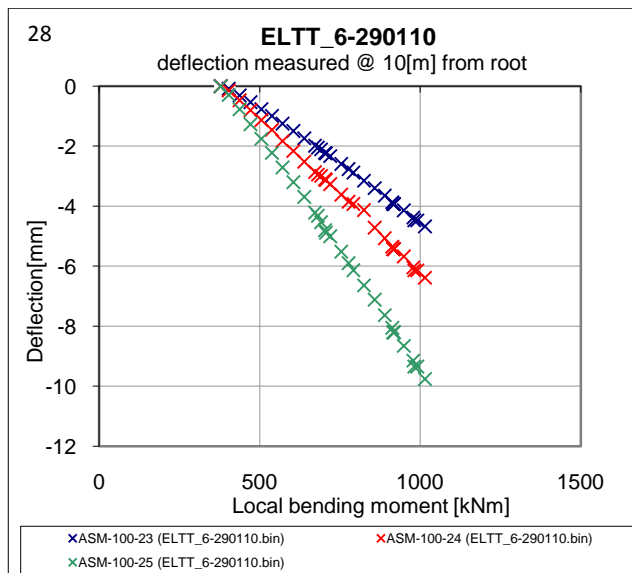


Figure 3.6. *ELTT_6_290110*
10m flapwise deflection

First pull at 80% Risø load (without the invented reinforcement and reinforcement of the maintenance hole). The maximum deflection is 10mm.

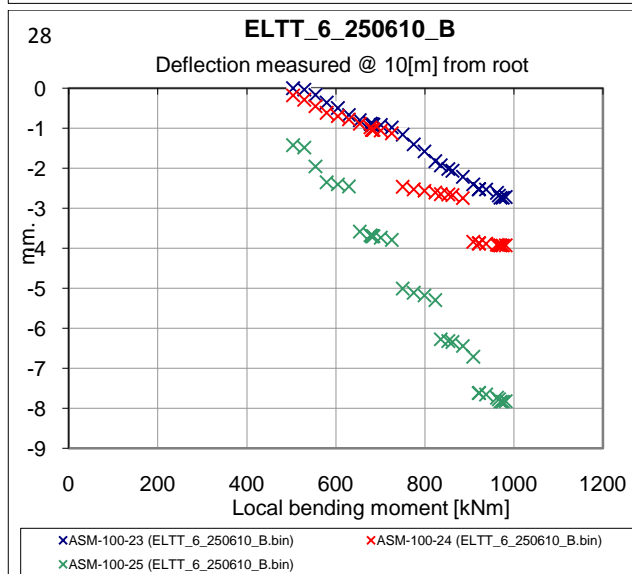


Figure 3.7
ELTT_6_250610_B 10m
flapwise deflection

Second pull at 80% Risø load (without the invented reinforcement and with the reinforcement of the maintenance hole). The maximum deflection is 8mm.

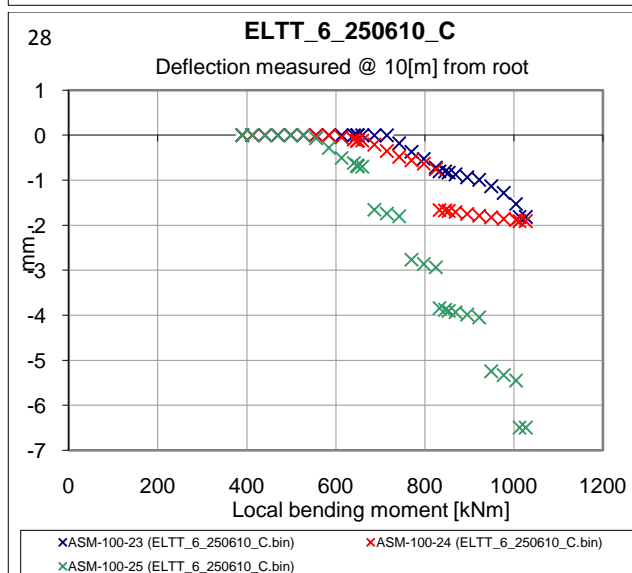


Figure 3.8
ELTT_6_250610_C 10m
flapwise deflection

Third pull at 80% Risø load (without the invented reinforcement and with the reinforcement of the maintenance hole). The maximum deflection is 6.5 mm.

3.3 Strain Measurements at the Middle of the Trailing Edge Panels

Strain measurements at the middle of the trailing edge panels were compared before and after reinforcing the maintenance hole in the web. The point for the comparison is called D_p , its location is presented in Figure 2.4.

The pull performed before implementing the maintenance hole reinforcement is *ELLT_6_290110* and the one with the reinforcement is *ELLT_6_250610_C*.

The difference can be seen in the longitudinal strains around 4m and 5m.

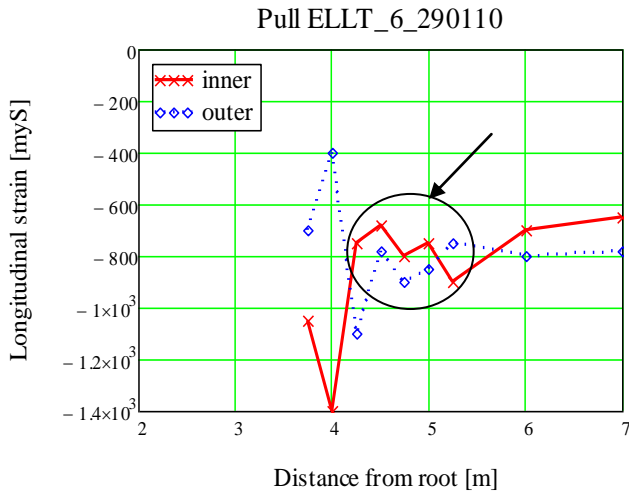


Figure 3.9 Longitudinal strain at the middle of the panels (D_p) for the blade before the maintenance hole in the web was reinforced.

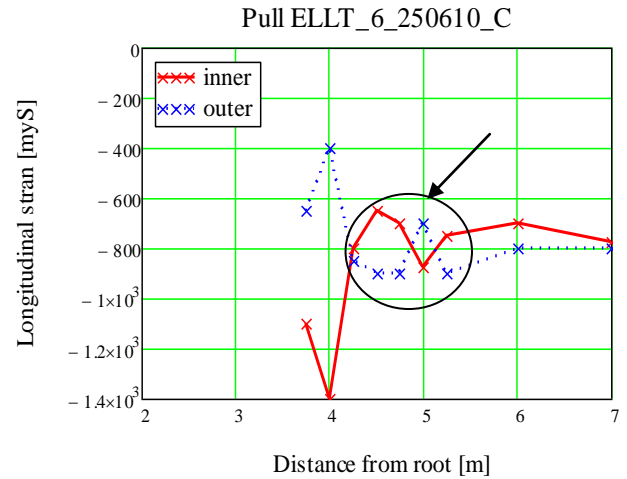


Figure 3.10 Longitudinal strain at the middle of the panels (D_p) for the blade after the maintenance hole in the web was reinforced

The changes could be caused by the reinforcement of the maintenance hole but other explanations might be possible.

When the tests *ELLT_6_290110* and *ELLT_6_250610* were performed, the blade was monitored with acoustic sensors in 4m and 11.5 m. The results from these measurements did not indicate that any damage occurred to the blade during test, see Appendix C.

In Appendix B the results from pulls with 80% Risø loads and at 60% Risø loads with the invented reinforcements can be found.

The remaining measurements at 60% Risø load are documented in the previous report, see ref. [1].

4. Structural Solution under Investigation

4.1 The Patent / The invention

Out of plane deformations of wind turbine blade trailing edge panels cause peeling stresses in the trailing edge that often result in fatigue failure in the trailing edge adhesive joint. This phenomenon is presented in Figure 4.1. The load-carrying box girder is also attached to the outer skin (aerofoil) with an adhesive joint sensitive to peeling stresses. This can lead to another failure, i.e. skin debonding, see ref. [7] and [8].

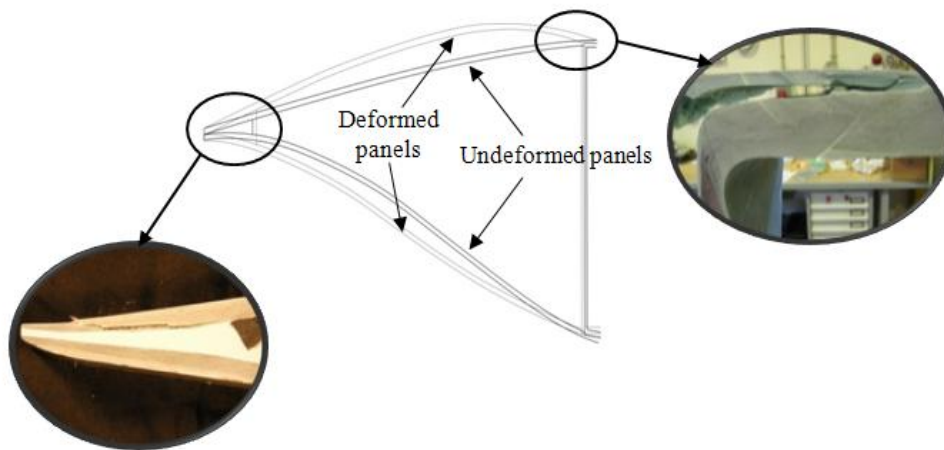


Figure 4.1. Sketch of the trailing edge shells with out of plane deformations. The close ups show fatigue failure at the trailing edge as well as debonding of the outer skin on the box girder.

The failure in adhesive joints might be addressed by preventing the panels' deformations as in the patented solution presented in Figure 4.2. Implemented connecting wires (or thread) prevent from urging the two connected points away from each other, strengthening the shell against deformation.

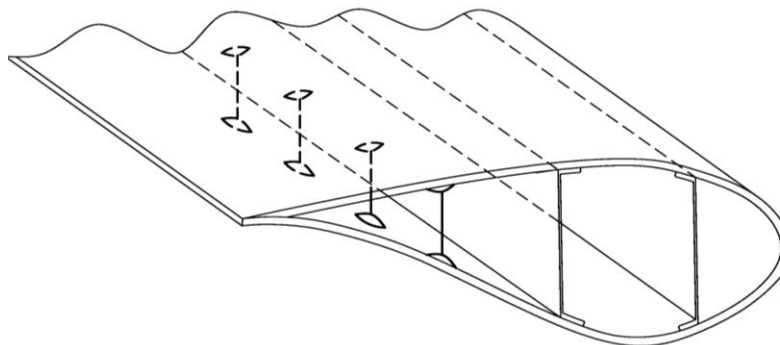


Figure 4.2. Reinforcement solution with the trailing edge panels coupled. Patent E, ref.[2].

4.2 Measurements for Prove of Concept

The experiments presented in this section are from tests performed in order to investigate the influence of the reinforcement on the structural behaviour of the blade cross-section. The implementation of the reinforcement is shown in Figure 4.3, where trailing edge panels were coupled with 6mm nylon line (called wires). This coupling was established between 3.5m to 4.5m.

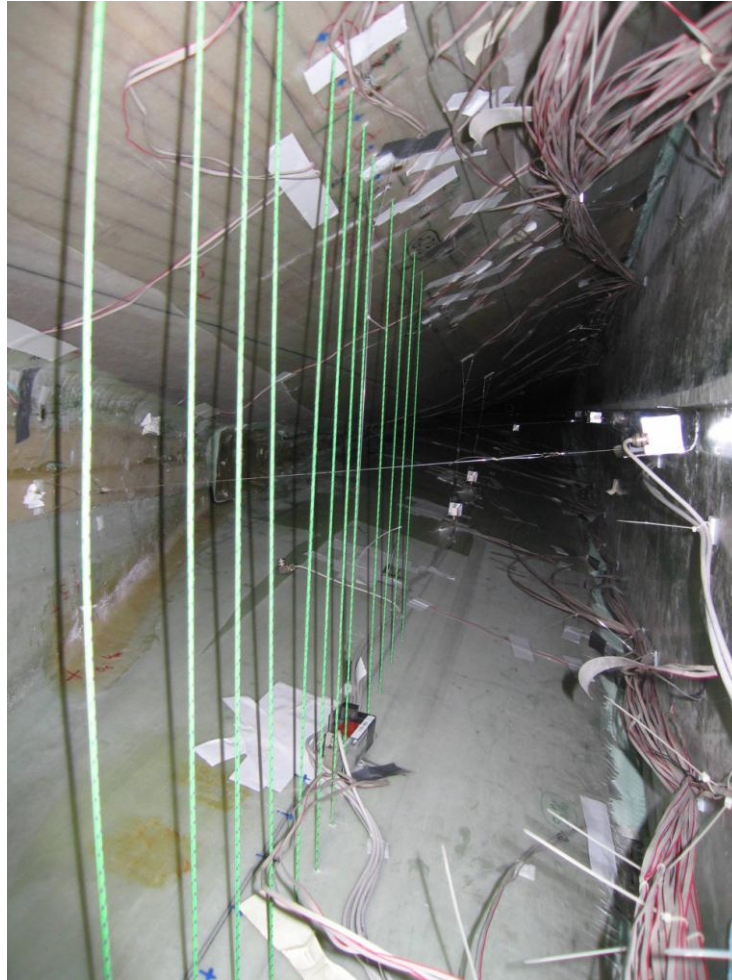


Figure 4.3. Photo inside the blade showing the reinforcement between the panels.

The test was conducted as described in ref. [1], and the measurements were compared to sections in the relevant area. In order to capture the magnitude of the forces in the reinforcement wires, three force transducers were connected to the wires. Figure 4.4 presents the results from these transducers at pulls with 60% Risø load. The result shown is between 30% and 60% Risø load, and before the pulls were performed the wires were pre-stressed to around 100N. As depicted in the figure, the maximum forces were measured to be 270N.

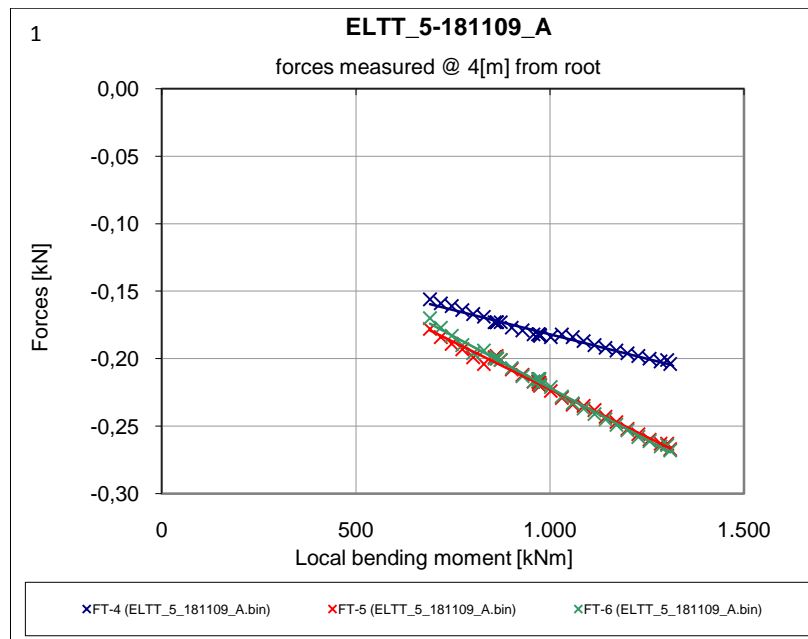


Figure 4.4. Graphs showing the forces in the reinforcement wires during testing.

Appendix A presents the measurement equipment placement for this test. The data from the measurement shown by means of graph tool can be found in Appendix B.

5. Results With and Without Reinforcement

This section presents the comparison of results obtained during full scale testing of the blade with the invented reinforcement and the blade without this reinforcement. The results for 60% Risø load from full scale test without reinforcement are presented in the previous data report ref. [1] and the ones from pulls with the reinforcement can be found in Appendix B.

5.1 Overview of the Deformation

As the invented reinforcement is mounted in the middle of the trailing edge panels, it is suitable to start the investigation by comparing the deformation at this position before and after the reinforcement. In Figure 5.1 and Figure 5.2 the deformations are compared, respectively at the pressure and the suction side.

The results presented are for 60% Risø load, as the measurement equipment for these measurements was removed at 80% Risø load. This was done because the frames used for these measurements would disturb the DIC measurements.

It is visible in Figure 5.1 presenting the pressure side that the deformation at 4m is reduced when the blade is reinforced. The difference in magnitude of the deformation is 1mm, so the deformation has been reduced by approximately 20%. It shows that the reinforcement reduces the maximum deformation, where the reinforcement is placed. However, at the same time the reinforcement increases the area with large deformation amplitude in the area towards the tip where there is no reinforcement. The curve of the deformation of the reinforced blade shows a double wave. This wave appears in other measurements as well. The deformation shown is moving toward the tip.

Figure 5.2 presents similar results for the suction side. The deformation on this side is somewhat smaller than on the pressure side, and the behaviour of the deformation with and without the reinforcement is similar. In this figure, the sign of the presented deformation results are reversed according to the sign of the measurements in order to illustrate that the panels are moving apart from each other.

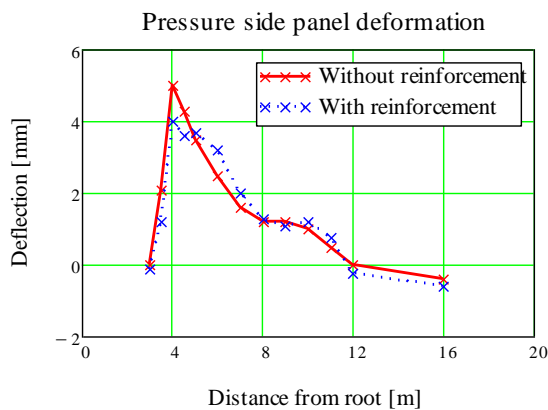


Figure 5.1 Comparison of the deflection measured in the middle of the pressure side panel for the blade with and without reinforcement.

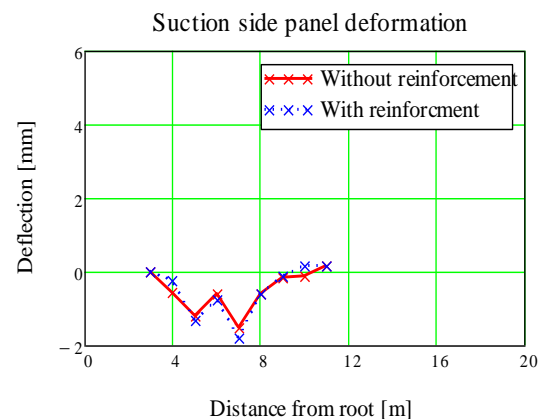


Figure 5.2. Comparison of the deflection measured in the middle of the suction side panel for the blade with and without reinforcement.

5.2 Strain Result Study

In this section, the strain measurements at relevant locations on the blade are presented in order to study the effect of the reinforcement. Of interest is the strain measurement at the middle of the panels as the reinforcement is acting in this position. This position is denoted as D , see Figure 5.3. The reinforcement is to prevent problems at the adhesive joints at the trailing edge, position A , and between the box and the panels, position E , and they are presented as well.

As the change in suction side deformation is not significant, only results from pressure side and the trailing edge are presented further.

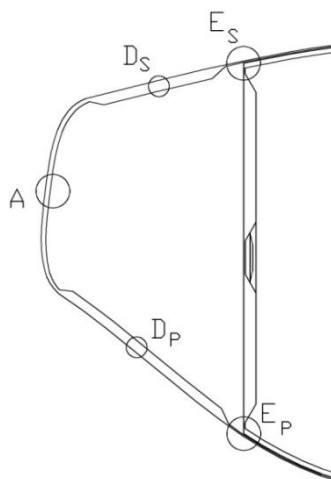


Figure 5.3. Positions of the measurements crucial for the investigations presented in this section.

Strain measurements results for each position are presented separately. The first results are at D_P . These strains are presented for both 60% Risø load and for 80% Risø load, since the web has been reinforced in between the measurement at 60% Risø load and 80% Risø load.

Figure 5.4 to Figure 5.11 are all strain measurement at point D on the pressure side panel. The results are shown for the area around 4.5m.

Figure 5.4 and Figure 5.5 are longitudinal and transversal strain for 60% Risø load and with the invented reinforcement between the panels.

Figure 5.6 and Figure 5.7 shows the same measurement as the above but without reinforcement.

Figure 5.8 and Figure 5.9 present longitudinal and transversal strain for 80% Risø load with the invented reinforcement. In these pulls the maintenance hole in the web was reinforced.

Figure 5.10 and Figure 5.11 the same measurement as the previous ones but without the invented reinforcement.

Figure 5.4 presents strain results in the longitudinal direction measured on the pressure side at position D (in the middle of the panel) throughout the region of interest. It indicates a significant deformation around 4m section. Comparison between measurements in Figure 5.4 and in Figure 5.6 (the same measurement without reinforcement) shows that the maximum strains, as expected, are reduced as the panel deformation is prevented around 4m in the reinforced blade.

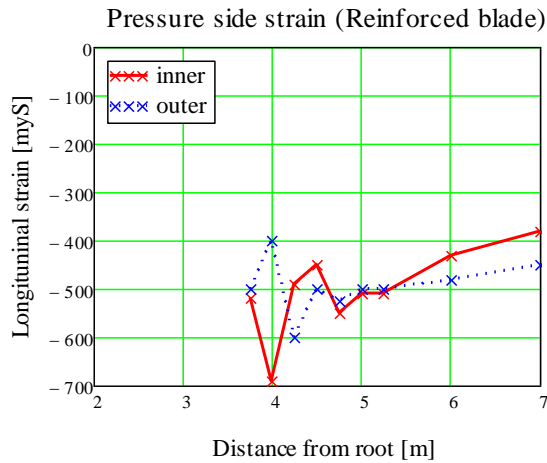


Figure 5.4. Strain in the longitudinal direction (1) at position D (in the middle of the panel) at the pressure side. The measurements were taken for 60% loads and with the reinforcement implemented.

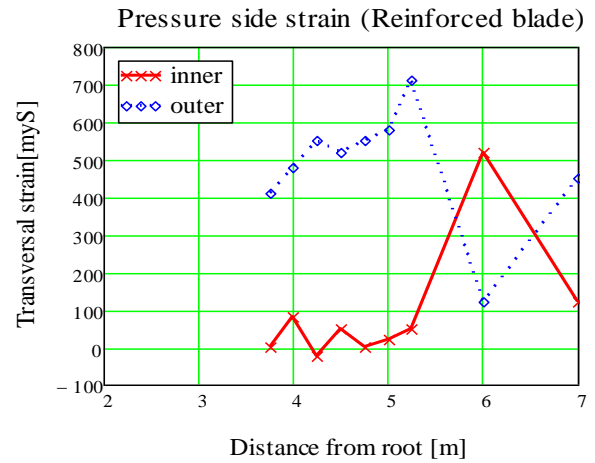


Figure 5.5. Strain in the transversal direction at position D at the pressure side. The results are for the reinforced blade at 60% load.

Figure 5.5 presents strain results for transversal direction. It shows that a significant, although smooth and not localised, deformation is formed also in the transversal direction. It indicates some characteristic of a double-wave. Comparison of the results in Figure 5.7 with those in Figure 5.5 (reinforced) clearly shows that the reinforcement has also an influence on the transversal strain at that region.

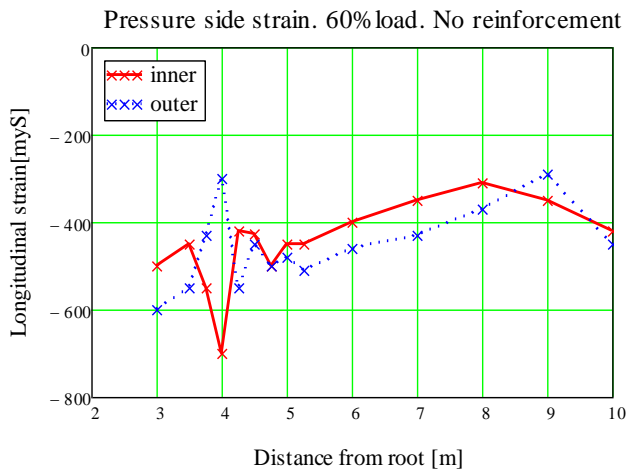


Figure 5.6 Strain in the longitudinal direction at 60% load for the blade without reinforcement

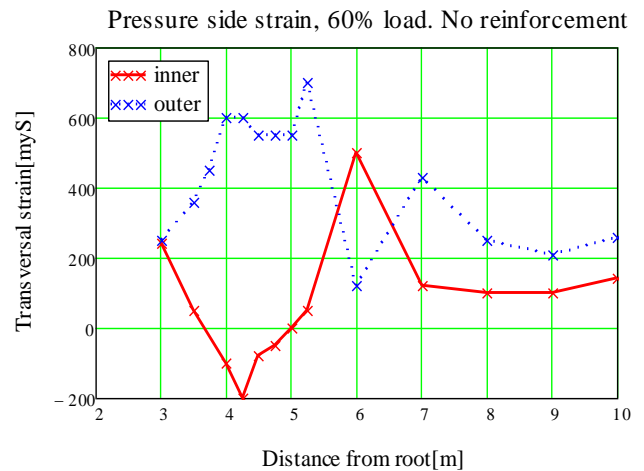


Figure 5.7. Strain in the transversal direction at 60% Risø load for the blade without reinforcement.

The results shown in Figure 5.8 to Figure 5.9 are measured at the position *D* on the pressure side as well. However, this time the load is 80% of Risø load, and these tests were performed after the maintenance hole was reinforced.

Pull called *ELLT_6_250610_A* is performed with the reinforced blade, and pull *ELLT_6_250610_C* is without reinforcement.

The results from these tests are similar to the test from 60% Risø load.

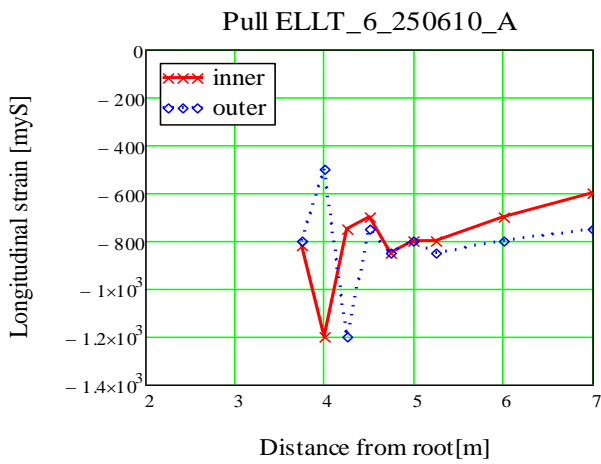


Figure 5.8. Strain in the longitudinal direction at 80% Risø load for the reinforced blade. Before this measurement the maintenance hole in the web was reinforced too.

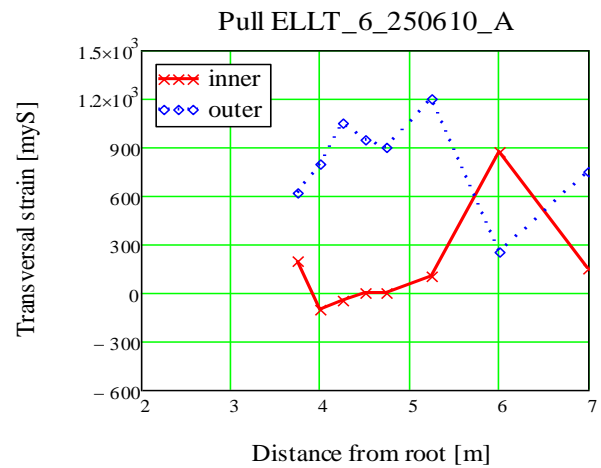


Figure 5.9. Strain in the transversal direction. The blade is reinforced in the panels and the maintenance hole web is reinforced as well.

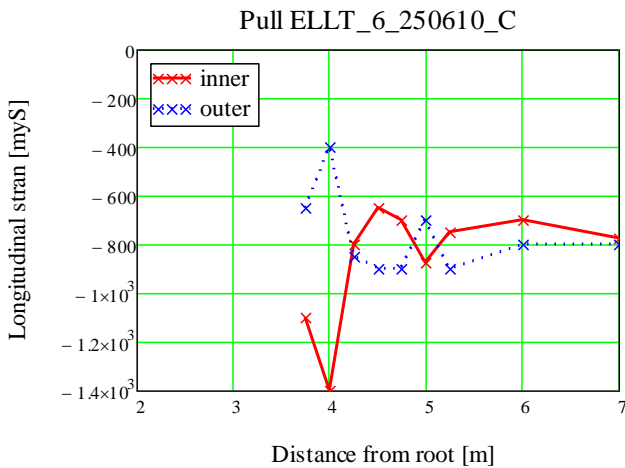


Figure 5.10 Strain measured in the longitudinal direction for 80% Risø load. There is no reinforcement between the panels.

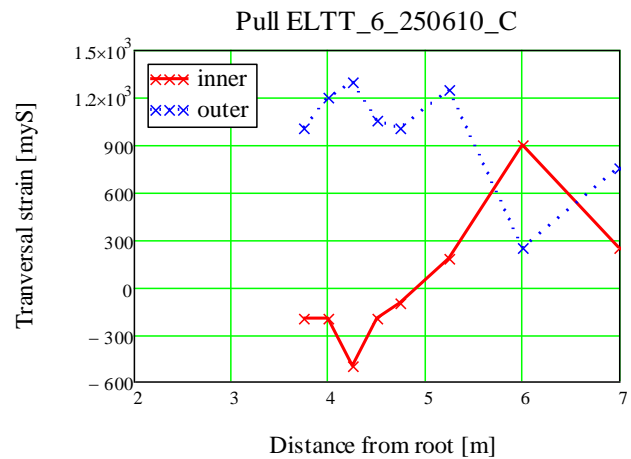


Figure 5.11 Strain measured in the transversal direction for 80% Risø load. The panels are not reinforced.

The reinforcement investigated is invented in order to prevent failure in the adhesive joints. Therefore, the strain measurements at the adhesive joints in the trailing edges, position A, and at the adhesive joints between the box and the panels, points E, are examined.

In Table 5.1 and Table 5.2, the strain measurements at the trailing edge, (A) are presented at 4m for the blade both with and without the reinforcement. In Table 5.3 and Table 5.4 results from strain measurements in the same section at the adhesive joints between box and panels (point E) are presented.

The results are presented for 60% Risø load, as these measurements were not performed at 80% Risø load.

Table 5.1 Strain measurements at the trailing edge adhesive joint for the test with reinforcement.

Reinforced blade:		Strain measurement at trailing edge		
Distance from root [m]	A_{o1}	A_{o2}	A_{i1}	A_{i2}
3	-810		-710	
4	-900	-100	-750	750
5	-900		-900	

Table 5.2 Strain measurements at the trailing edge adhesive joint for the test without the reinforcement.

Blade without:		Strain measurement at trailing edge		
Distance from root [m]	A_{o1} [μ S]	A_{o2} [μ S]	A_{i1} [μ S]	A_{i2} [μ S]
3	-800		-710	
4	-900	-200	-700	800
5	-890		-900	

In the 4m section the reinforcement influence on the panels is most pronounced. Thus, the results from the strain measurements at the adhesive joints between the box and the panels are presented for this section.

Table 5.3. Strain measurements on the inner and outer side of the pressure side panel at the adhesive joints at box girder (position E), 4m section. Comparison of the results for the test with and without reinforcement.

Pressure side strain measurement at 4m, E_p , with and without reinforcement		
	E_{po1} [μ S]	E_{po2} [μ S]
With reinforcement	-340	165
Without	-320	120

Table 5.4. Strain measurements on the inner and outer side of the suction side panel at the adhesive joints at box girder (position E), 4m section. Comparison of the results for the test with and without reinforcement.

Suction side strain measurement at 4m, E_p with and without reinforcement				
	E_{so1} [μ S]	E_{so2} [μ S]	E_{si1} [μ S]	E_{si2} [μ S]
With reinforcement	-120	100	-120	160
Without	-115	130	-115	120

5.3 Influence of the Reinforcement on the Shear Distortion

The trailing edge panels and the box girder are connected with adhesive joints. Therefore, the reinforcement might influence the box behaviour and was therefore examined. The measurements presenting the deformation of the box are therefore compared to tests with and without the panel reinforcement. Figure 5.12 presents the positions, where the measurements discussed in the following table were taken.

Table 5.5 and Table 5.6 give the box girder deformation measurement data for 60% Risø load without and with the reinforcement. The results in 3m from these two tests indicate that the reinforcement might have influence on the distortion of the box.

Table 5.5. Measurements of shear deformation inside the box for the unreinforced blade

section	G_s-E_p	E_s-G_p	I-J	J-K	D_s-D_p
3 m	-0.4	0	2.5	x	0
4 m	-1.1	0	1.5	0	5.5
5 m					4.3
6 m					3.2
7 m	-1.6	0.7	0.4	-0.07	2.7
10 m	-0.7	0.7	0.2	-0.05	0

Table 5.6. Measurements of shear deformation inside the box for the reinforced blade

section	G_s-E_p	E_s-G_p	I-J	J-K	D_s-D_p
3 m.	-0.65	0	2.5	x	0
4 m.	-0.9	0	2.5	-0.1	3.7
5 m.					4.3
6 m.					3.2
7 m.					2.8
10 m.	-0.9	0.9	-0.03	0.16	0.05

The maintenance hole in the trailing edge web were reinforced between the first and second pull at 80% Risø load, as presented in Section 2. Therefore, comparison of tests with and without the invention at 80% Risø load is only possible after the maintenance hole reinforcement is implemented. However, the test performed on January 29th 2010 (290110) without the web reinforcement and without the invented panel reinforcement is presented in order to give an impression of the influence of the maintenance hole reinforcement on the box girder.

In Table 5.7, results called 250610_A are the test with the invention implemented, whereas 250610_B and 250610_C are tests without it. The 4m section results for tests B and C differ slightly. But they together differ significantly from pull (A) with the reinforcement. The shear distortion is much more pronounced in the reinforced blade, see Table 5.7

Table 5.7. Measurements inside the blade with and without the invented reinforcement.

	G_s-E_p	E_s-G_p	I-J	J-K	D_s-D_p
4 m.					
290110	-2.2	1.7	2.2	1	11
250610_A	-3	2	3.5	0	7
250610_B	-1	1.2	3.5	0	11
250610_C	-0.6	0.7	3.5	0	11
5 m.					
290110					7.3
250610_A					6.5
250610_B					7
250610_C					6.8
6 m.					
290110					5.5
250610_A					5
250610_B					4.5
250610_C					4.5
7 m.					
290110					4.8
250610_A					4.3
250610_B					4.3
250610_C					4.3
10 m.					
290110	-2	2	-0.13	0.35	1.2
250610_A	-2.5	1	0	0	0.6
250610_B	-1.2	0.9	0	0.06	0.55
250610_C	-0.8	0.8	0	0	0.65

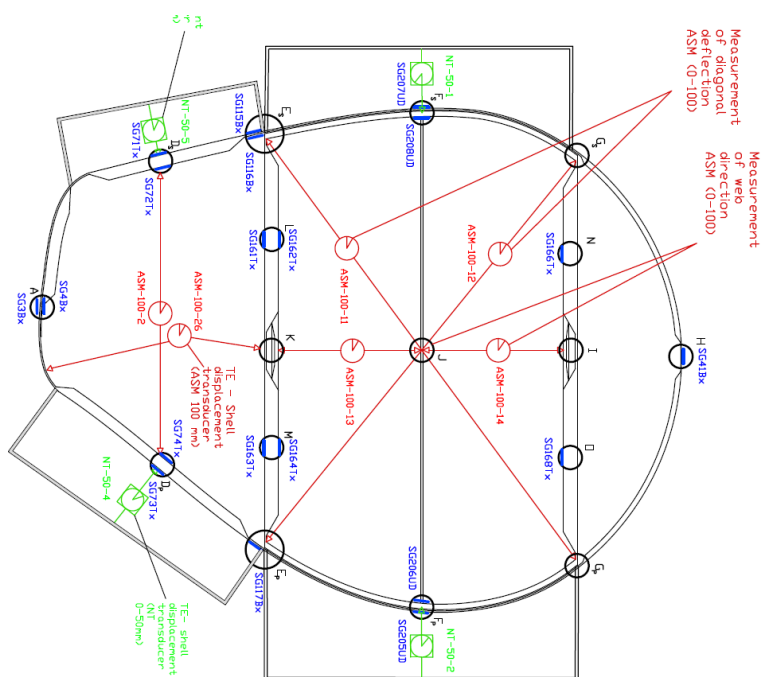


Fig. a

Fig. b

Figure 5.12. Fig. a. Scheme presenting positions for measurement equipment that gathered the data discussed in Table 5.7 (4m section is shown). Fig. b. Photo taken inside the blade showing the measurement equipment.

6. Digital Image Correlation (DIC) and FEM results

This section presents the results from the DIC measurement performed during tests with and without reinforcement. The comparison between the FEM analyses and DIC of the pressure side trailing edge panel (not reinforced) is presented as well. The FEM analysis of the panels in tension is studied together with the behaviour under compression.

6.1 DIC Comparison With and Without Reinforcement

The digital image correlation system (DIC), described in a previous data report, ref. [1], is used to document the behaviour of the panels between 3.5m and 5m sections. These measurements were performed at 60% load both with and without reinforcement of the panels. Figure 6.1 and Figure 6.2 present the measurements with and without the reinforcement respectively.

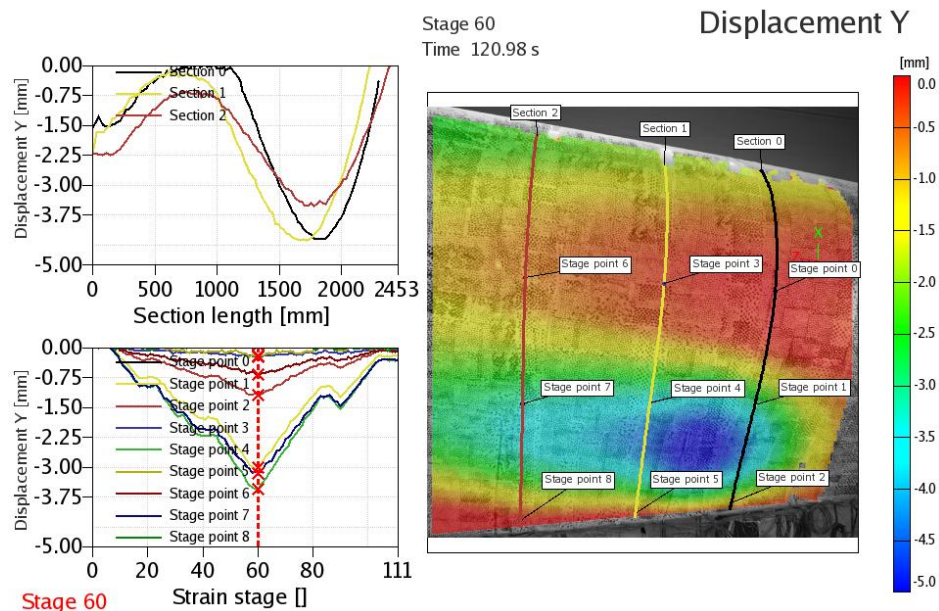


Figure 6.1 Snapshot from 3.5m - 5m section at 60% Risø load without reinforcement between the panels

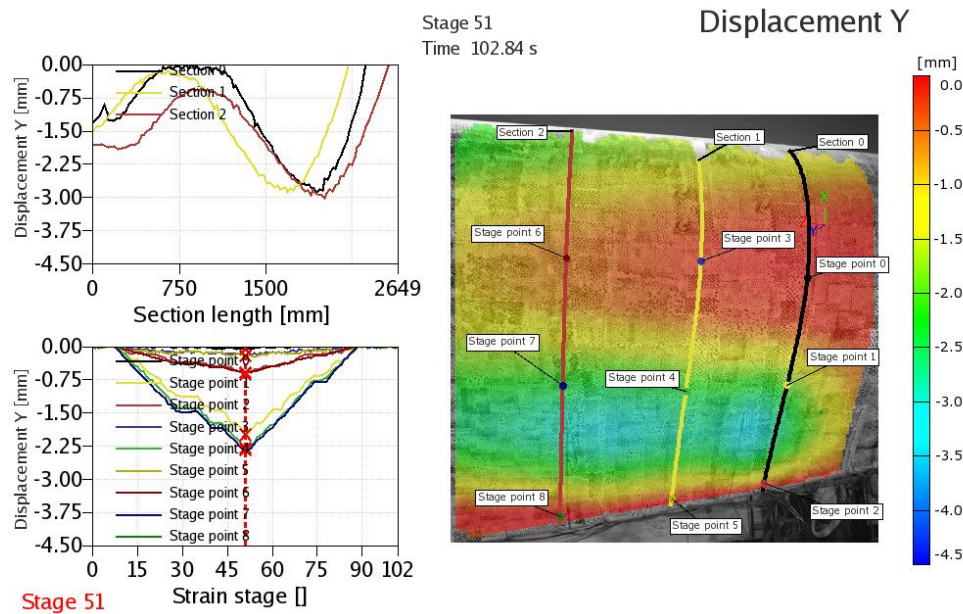


Figure 6.2 Snapshot from 3,5m-5m section at 60% Risø load with reinforcement between the panels.

These results show, confirming the displacement measurements presented in Section 5.1, that the displacement of the middle points of the panels is reduced when the blade is reinforced.

Figure 6.2 showing the displacement field of the panel with the reinforcement clearly indicates that there is a double wave. This behaviour was also revealed by the displacement measurements.

The DIC measurements in the same area at 80% Risø load display similar results except from the fact that the double wave is more pronounced at 60% Risø load, see Figure 6.3 and Figure 6.4.

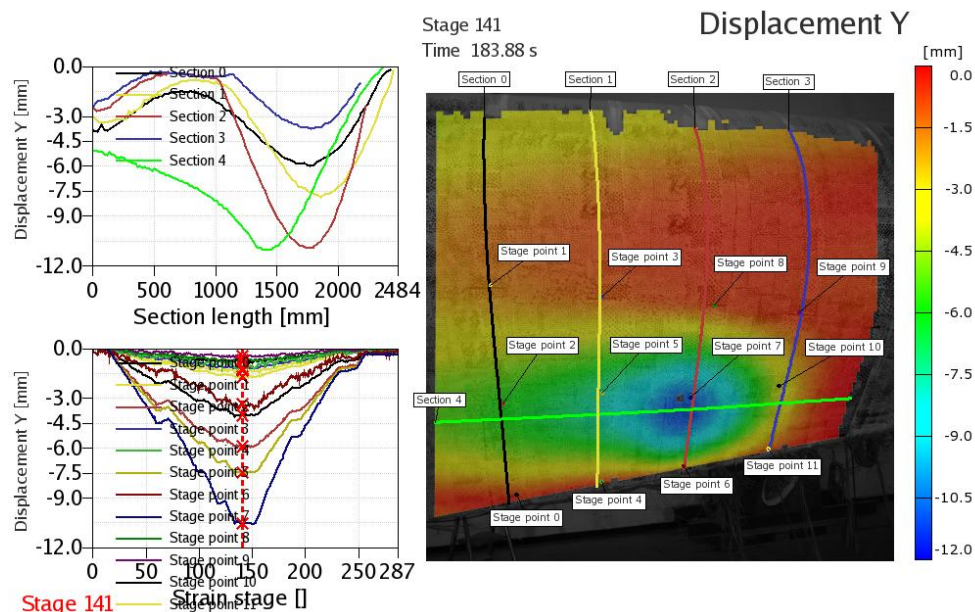


Figure 6.3 Snapshot from 3.5m - 5m section at 80% Risø load without reinforcement between the panels

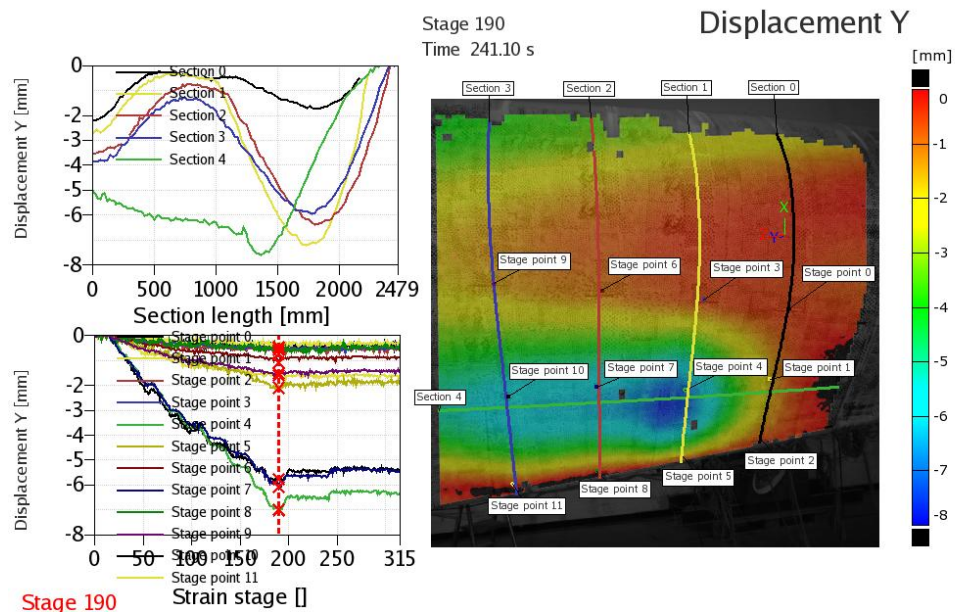


Figure 6.4 Snapshot from 3,5m-5m section at 80% Risø load with reinforcement between the panels.

More results from the DIC measurements can be found in Appendix D.

6.2 Comparison between FEM Analyses and DIC

In Figure 6.1 (without reinforcement) a double wave is visible, even if not evident. Comparing these results with the reinforced blade (Figure 6.2), implementing the reinforcement has ‘pulled’ the top of the waves away from each other.

The discussed double wave for the unreinforced blade was also recognised in FEM study. The deformation distribution field obtained by FEM was compared to that found with the DIC measurements. The results, presented in

Figure 6.5, confirm that the FE-model corresponds well with the full-scale test. In both cases, there appears a ‘double wave’ and there is no ‘phase shift’ of the deformation position. Some insignificant differences come from the fact that the frames of reference (black frames visible in

Figure 6.5a) was mounted in not precise positions. Nonetheless, the distribution is virtually identical both in shape and values attained.

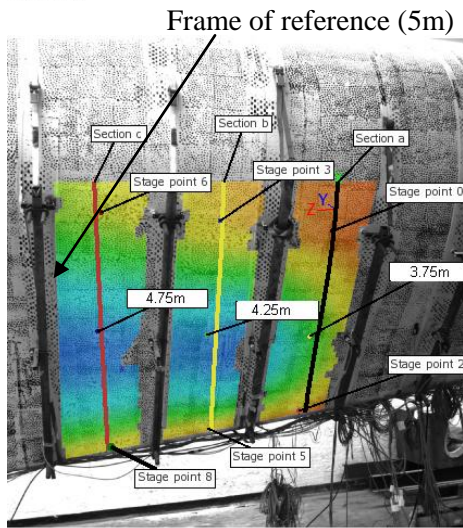


Fig. a

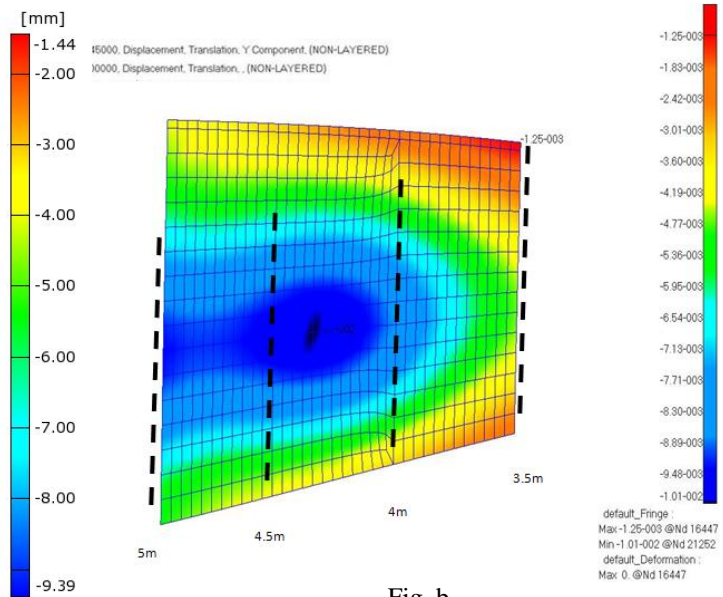


Fig. b

Figure 6.5 Comparison of experimental and numerical results for the out of plane deformation. Fig. a: Deformation distribution obtained with Aramis. Fig. b: FEM results from a corresponding load step in the same region. The scale has been adjusted for a better visualization of the comparison. From [5].

The results presented above come from an experiment performed during the summer of 2009. The experimental procedure has been further developed since that time. Nonetheless, the findings are relevant. It is further shown that the same behaviour was captured in the latest tests.

In Figure 6.6, a profile of the deformation obtained with FE analysis is presented. It shows the pressure side trailing edge panel deformation at several load increments. The displacement plotted is measured at the panel midpoints, which correspond to the point where the deformation reaches its highest amplitude. This figure demonstrates highly localized character of the deformation. It also visualizes the duplex shape of the deformation even in very early stage of its development. At 5% of load the amplitude is very small and the double wave is not easily visible, thus, these results were scaled 4 times.

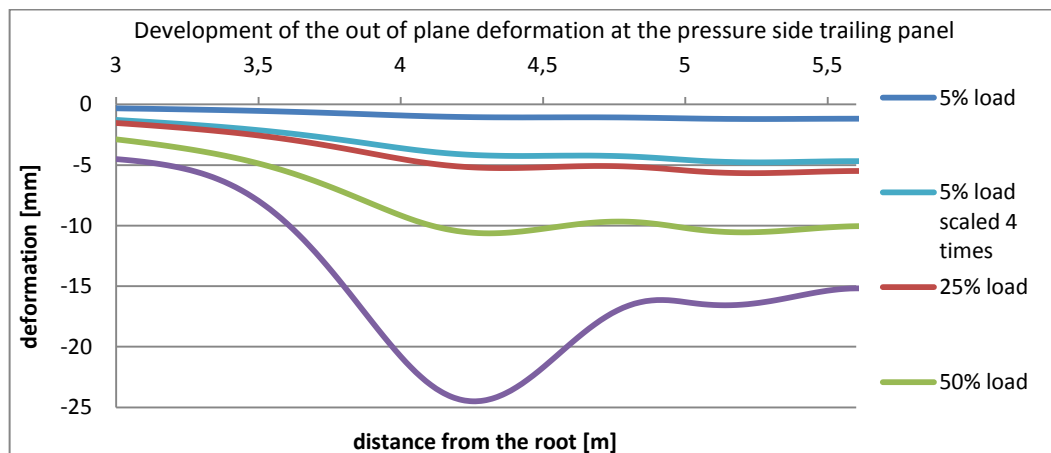


Figure 6.6. Development of the out of plane deformation profile at the pressure side trailing edge panel in the blades' root section. From [5].

6.3 Behaviour of the Panels under Tension

The study of the root region behaviour confirmed a structurally significant local deformation of the pressure side trailing edge panel. An investigation of the nature of deformation was conducted. The aim was to test if the nonlinear behaviour of the deformation is dominated by buckling. First, the strain results were studied and then to further test the hypothesis of buckling influence, the response of the panel subjected to tension was investigated.

Buckling occurs only in compression and that causes local compression. Therefore, if the studied panel in tension does not deform, it will indicate that the phenomenon may be caused by buckling.

In order to put the panel under tension, load was applied to the blade in Trailing Towards Leading edge direction (TTL). The trailing edge panel under this load is presented in Figure 6.7. Not only an oppositely directed (inwards) deformation occurs in tension but also it has a similar shape to the one observed in compression.

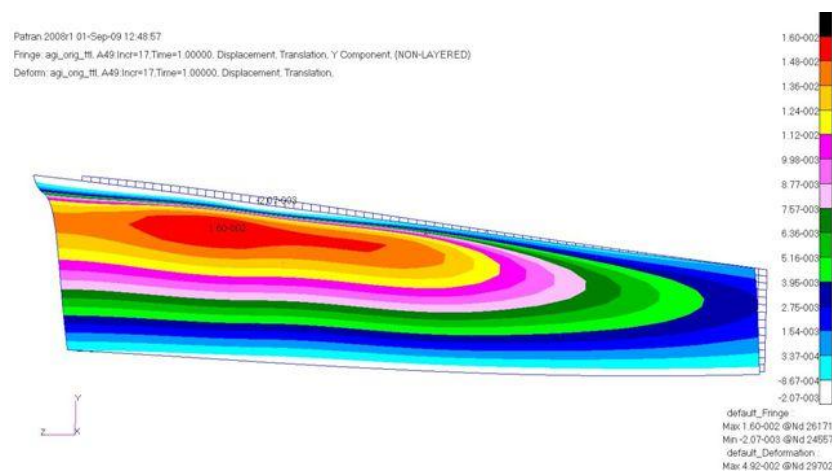


Figure 6.7. The pressure side trailing edge panel in tension (TTL loading of the blade). The fringe presents displacement transversal to the loading direction. From [5].

The local displacement in the point of the deformation's highest amplitude is presented in Figure 6.8. It is clearly visible that the deformation develops in the same non-linear manner achieving virtually the same value as in compression (the difference is 2%). More details on this study can be found in ref. [6].

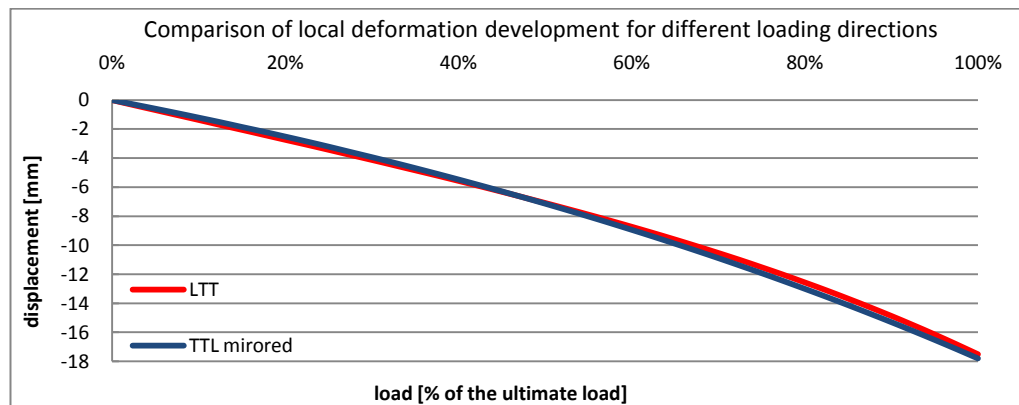


Figure 6.8. Local out of plane displacement comparison for tension and compression of the panel (corresponding to LTT and TTL load cases). From [5].

These results show that behaviour corresponding to the one observed in compression occurs for the panel in tension. Therefore it can be concluded that the investigated local deformation nonlinearity is not buckling driven. However, if the loading continues above the ultimate value it can be expected that the deformation will result in buckling occurrence.

It needs to be stressed that the deformation needs to be addressed independently of its nature. This is because the high deformation amplitude causes the failure in the adhesive joint.

7. Summary and Conclusion

This report presents tests carried out on a truncated blade from SSP technology A/S, for 60% and 80% Risø-defined load. The test at 80% Risø load was repeated before and after a maintenance hole in the web was reinforced. This reinforcement reflected on the measurement results. This data report contains the raw data from pulls with 80% Risø load and the results from pulls where the blade was reinforced according to a recently patented invention E, i.e. coupling of the trailing edge panels.

Test results with and without the reinforcement implemented were compared. It showed that the maximum amplitude of the trailing edge panel deformation was reduced by approximately 20%. However, at the same time the area of the deformation increased. Study of the strain at the adhesive joints with and without the reinforcement did not reveal significant difference. The measurements indicating the deformation of the box girder showed increase of the distortion behaviour when implementing the reinforcement.

The DIC measurements presenting the displacement field of the panel indicate that there is a double wave. This behaviour was also revealed by the displacement measurements. The DIC results also confirm that the displacement of the middle points of the panels is reduced when the blade is reinforced.

The FEM results for the not reinforced blade were compared to the DIC measurement and the agreement was satisfactory. The behaviour of the panel in tension is also presented briefly implying that the studied deformation is not buckling driven.

8. References

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9. Appendices

A List with measurement equipment and its placementp. 1

Strain gauge position extreme load
Group with deflection measurements
Section on the blade with measurement equipment

B Data presented by graph toolp. 15

B1 Measurement of pull with panel reinforcement.....p. 16
60% Risø load ELLT_131009_A

B1a Strain gauge measurement

B1b Deflection measurement

B2 Strain measurements of pulls with 80% Risø load..... p. 37

B2a ELLT_6_290110

B2b ELLT_6_250610_A

B2c ELLT_6_250610_B

B2d ELLT_6_250610_C

B3 Deflection measurements of pulls with 80% Risø load..... p. 98

B3a ELLT_6_290110

B3b ELLT_6_250610_A

B3c ELLT_6_250610_B

B3d ELLT_6_250610_C

C Acoustic emission.....p. 112

D DIC.....p. 118

Appendix A

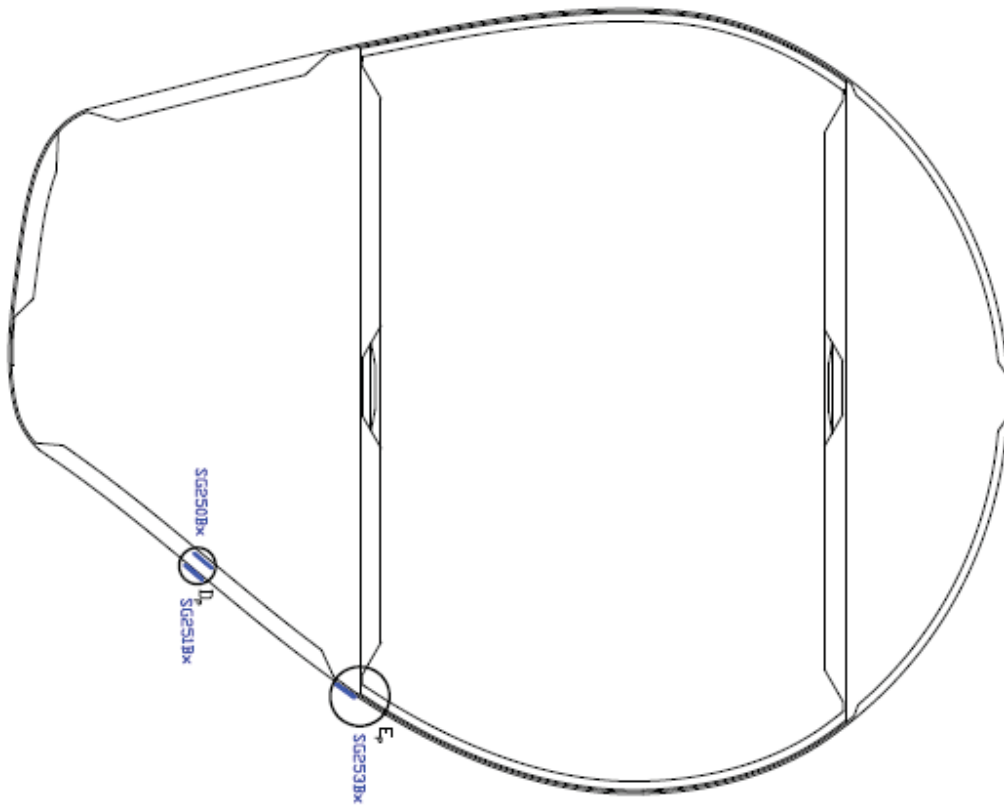
Table Strain gauges positions Extreme Loads

Amplifiers boxes	Ch-1																				Ch-2																				Ch-3																				Ch-4																				Ch-5																				Ch-6																				Ch-7																				Ch-8																				Ch-9																				Ch-10																				Comments																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						

Group 6 (Extreme load): The Group with deflection measurements

	1	2	3	4	5	6	7	8	9	10
A1	FT-1	FT-2	FT-3	ASM-2000-5	ASM-2000-6	ASM-2000-7	ASM-4000-2	ASM-2000-2	ASM-2000-3	ASM-2000-4
A2	ASM-4000-1	ASM-100-23	ASM-100-24	ASM-100-25	ASM-2000-1	empty	NT-100-6	empty	empty	empty
A3	NT-100-3	NT-100-4	NT-50-7	NT-50-8	NT-50-9	NT-50-10	NT-50-11	NT-50-12	empty	empty
A4	NT-100-1	NT-100-2	NT-50-1	NT-50-2	NT-50-3	NT-50-4	NT-50-5	NT-50-6	ASM-100-8	ASM-100-9
A5	ASM-100-10	ASM-100-11	ASM-100-12	ASM-100-13	ASM-100-14	ASM-100-17 (between I and K)	ASM-100-19	ASM-100-20	ASM-100-21	ASM-100-22
A6	ASM-100-1	ASM-100-2	FT-4	ASM-100-3	ASM-100-4	ASM-100-5	FT-5	ASM-100-6	FT-6	ASM-100-7

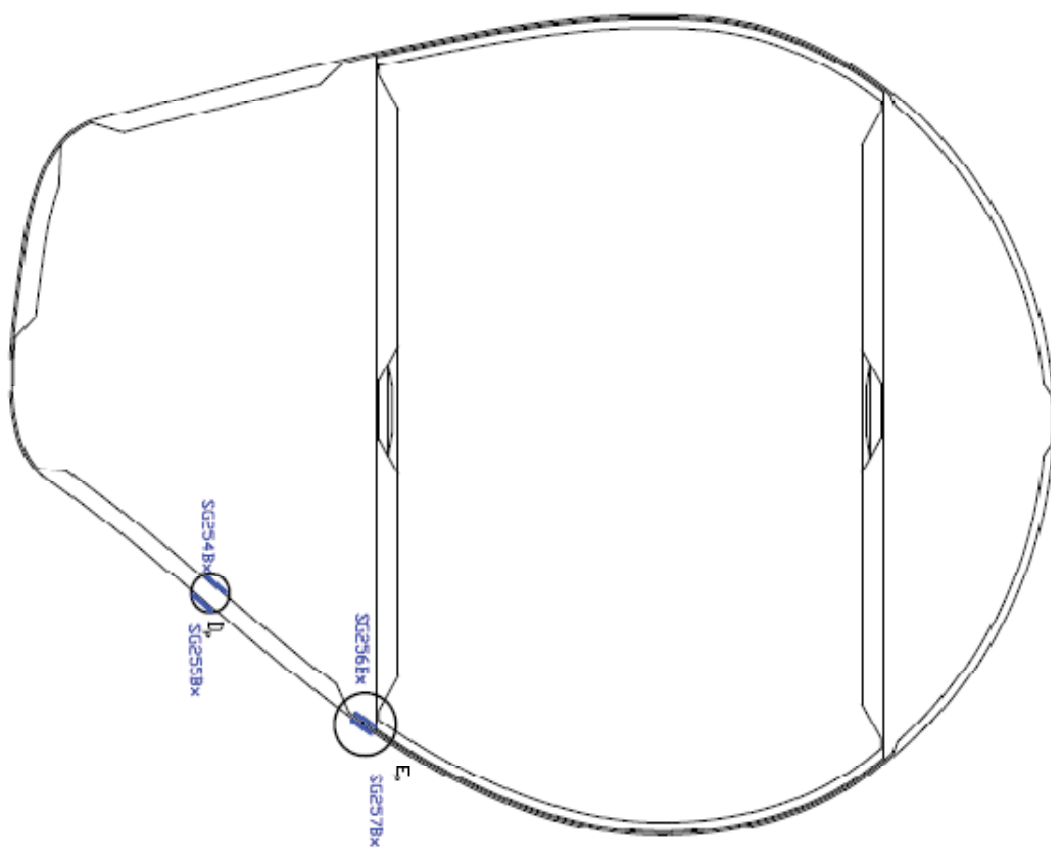
Section 3.5m based on the 3m. section



Measurement of diagonal deflection
ASM (0-100)



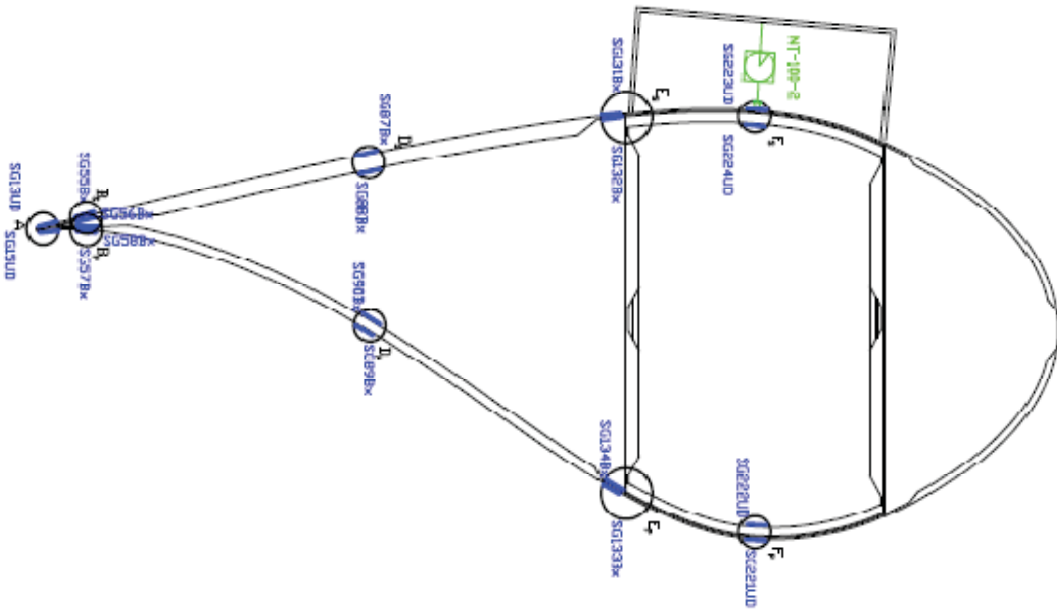
Section 4.5m based on the 3n. section



[illegible]

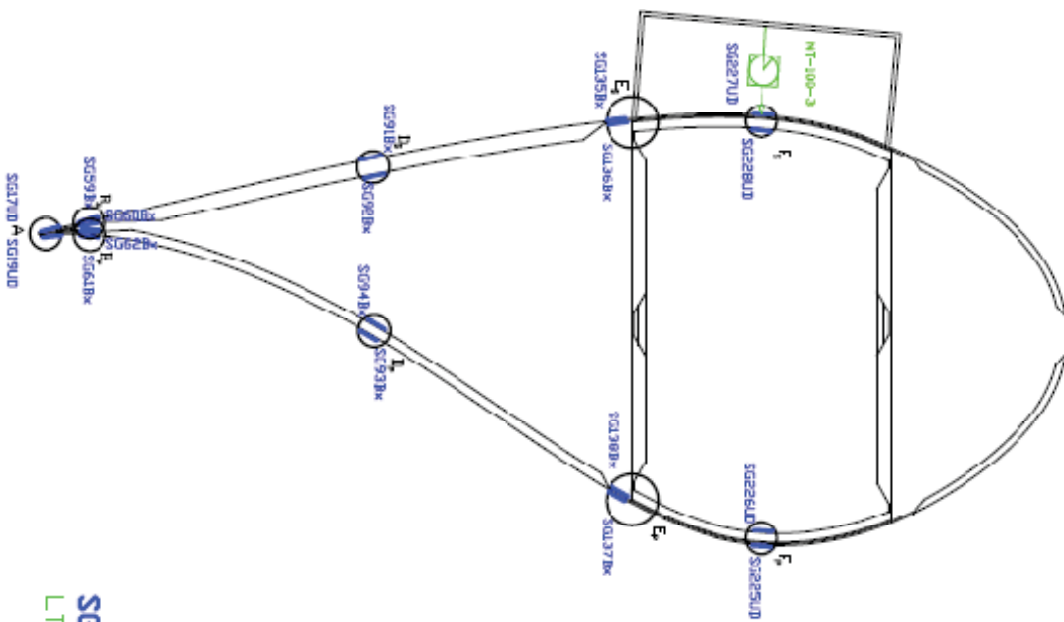
SG
LT-NT
LT-ASM

Section 3m based on 9m Section



SG
LT-NT

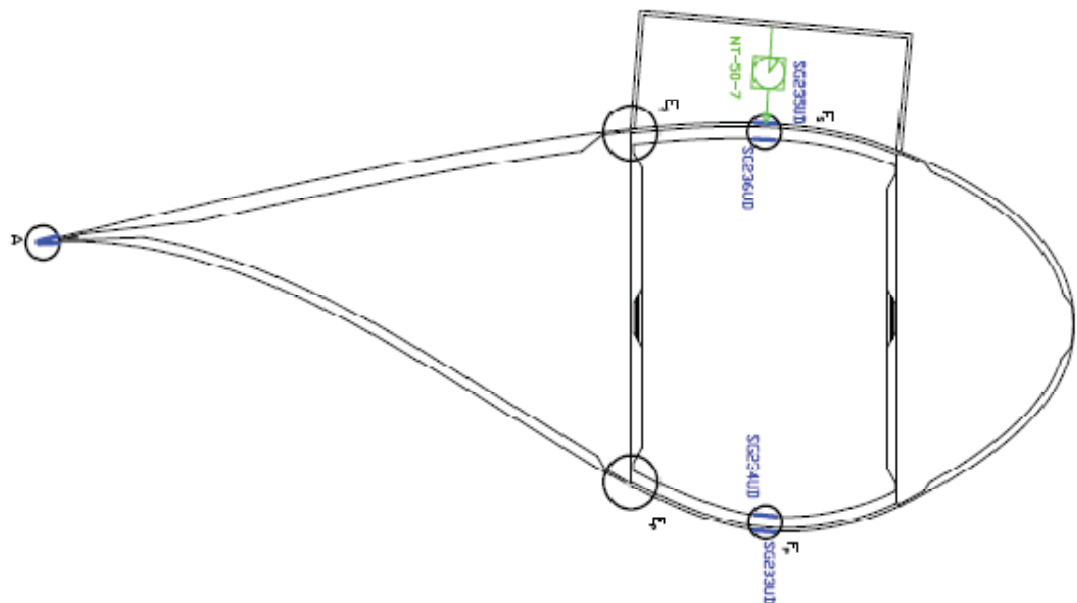
Section 9m



SG
LT-NT

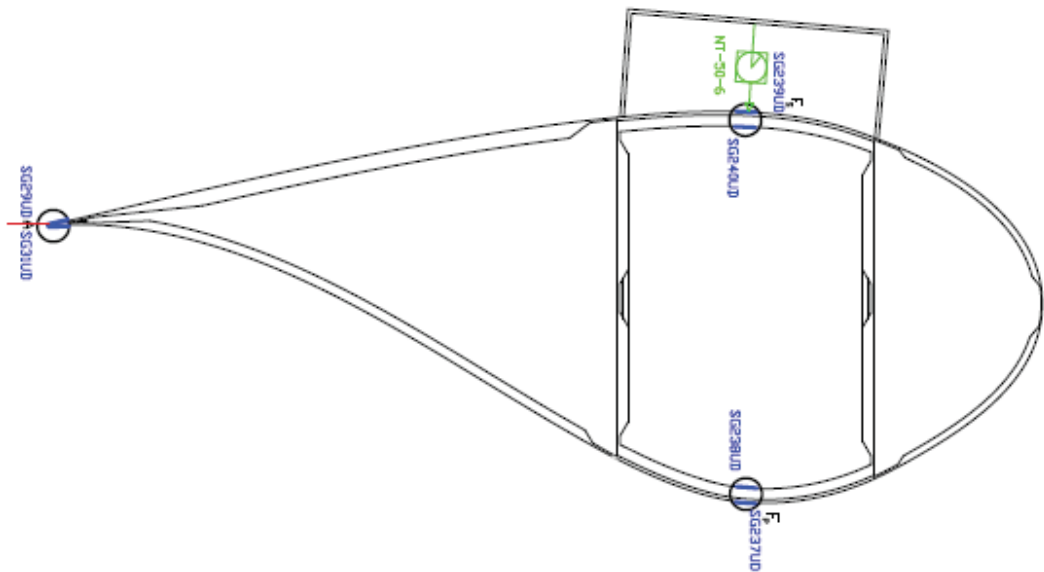
[illegible]

Section 11m based on 10m section



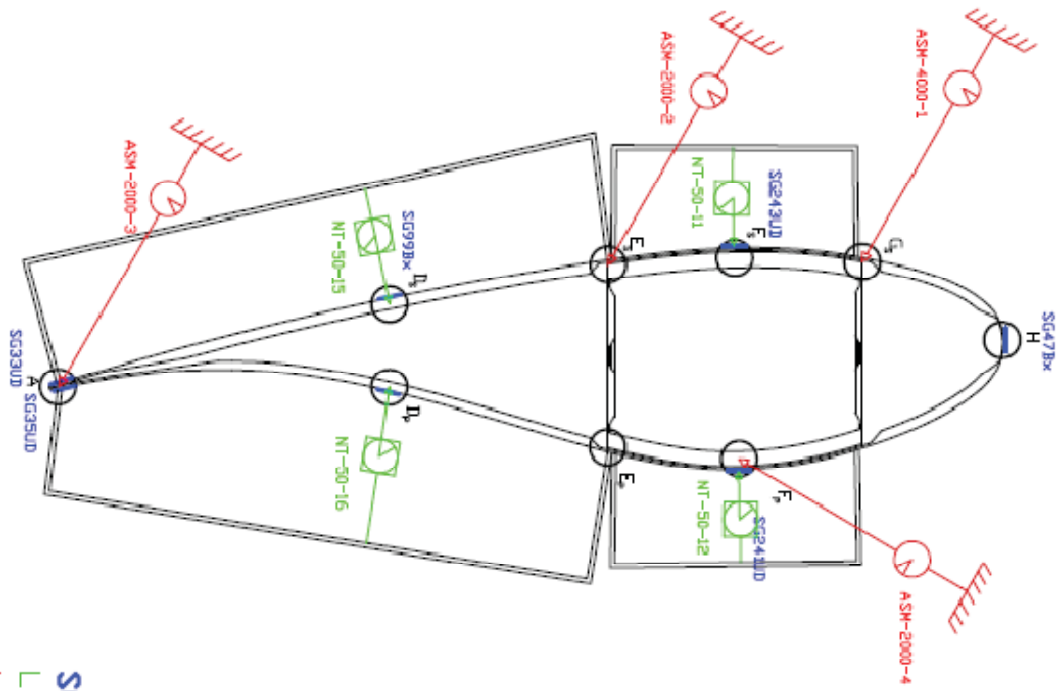
SG
LT-NT

Section 12m based on 10m section



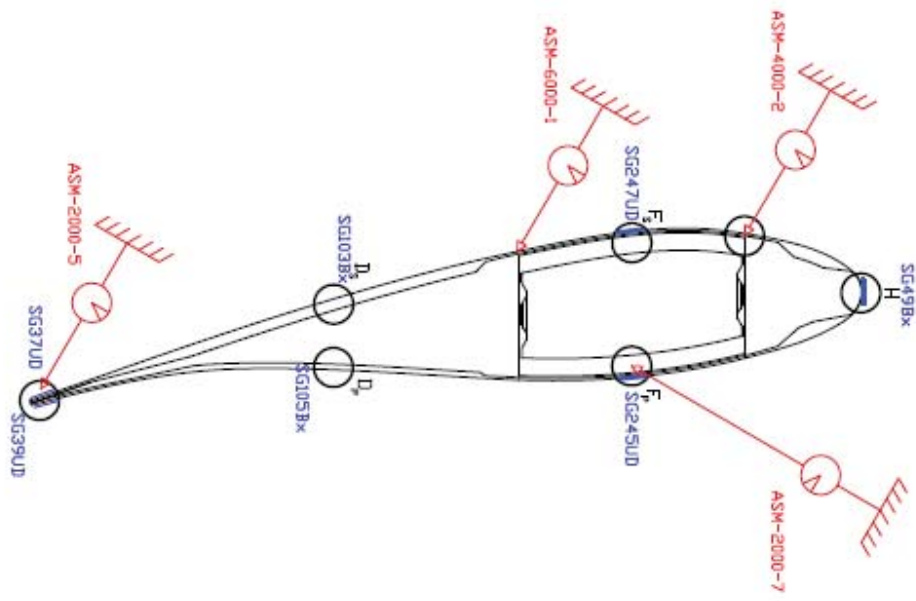
SG
LT-NT

Section 16m



SG
LT-NT
LT-ASM

Section 22m



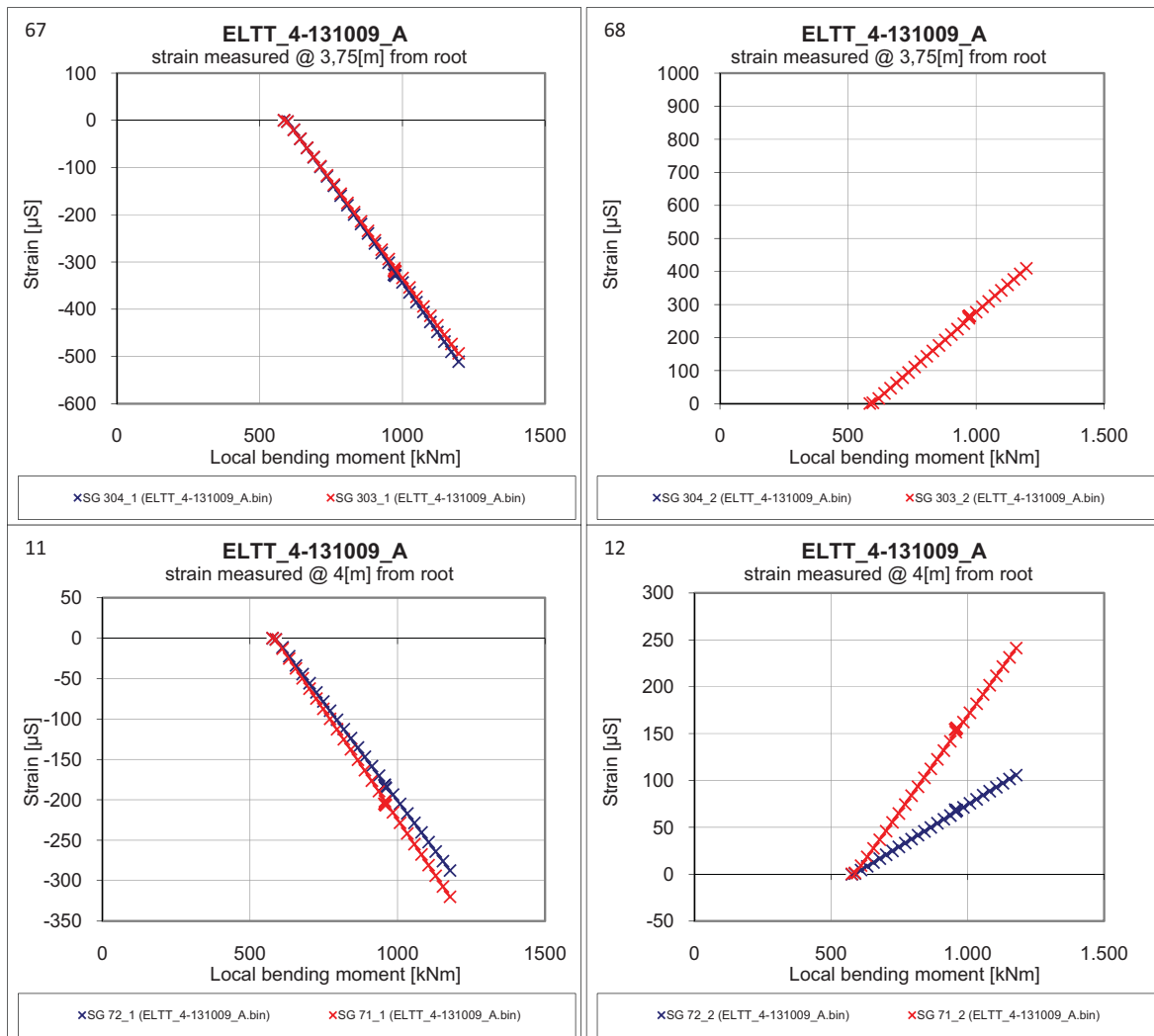
SG
LT-ASM

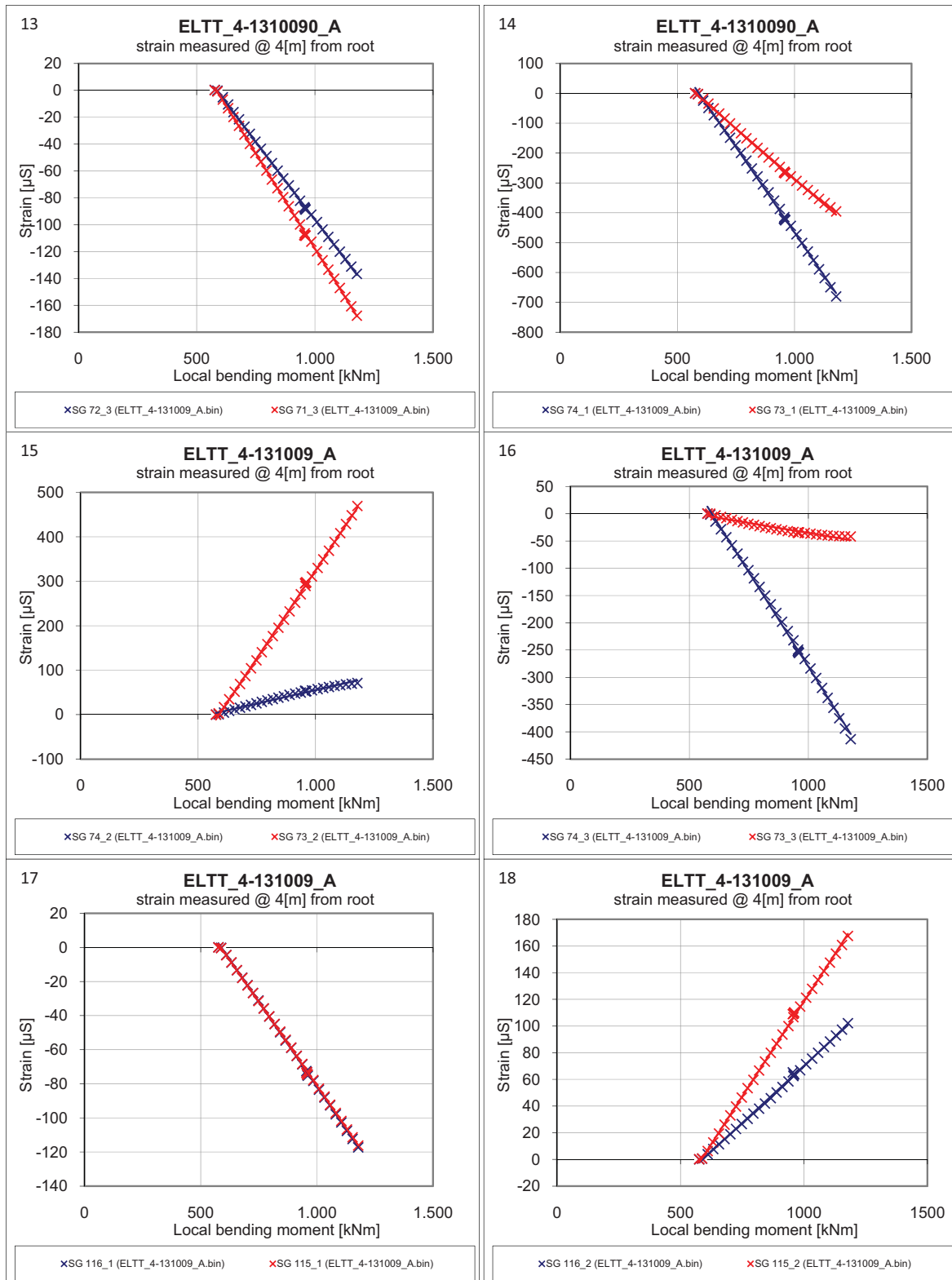
B Data presented by Graph tool

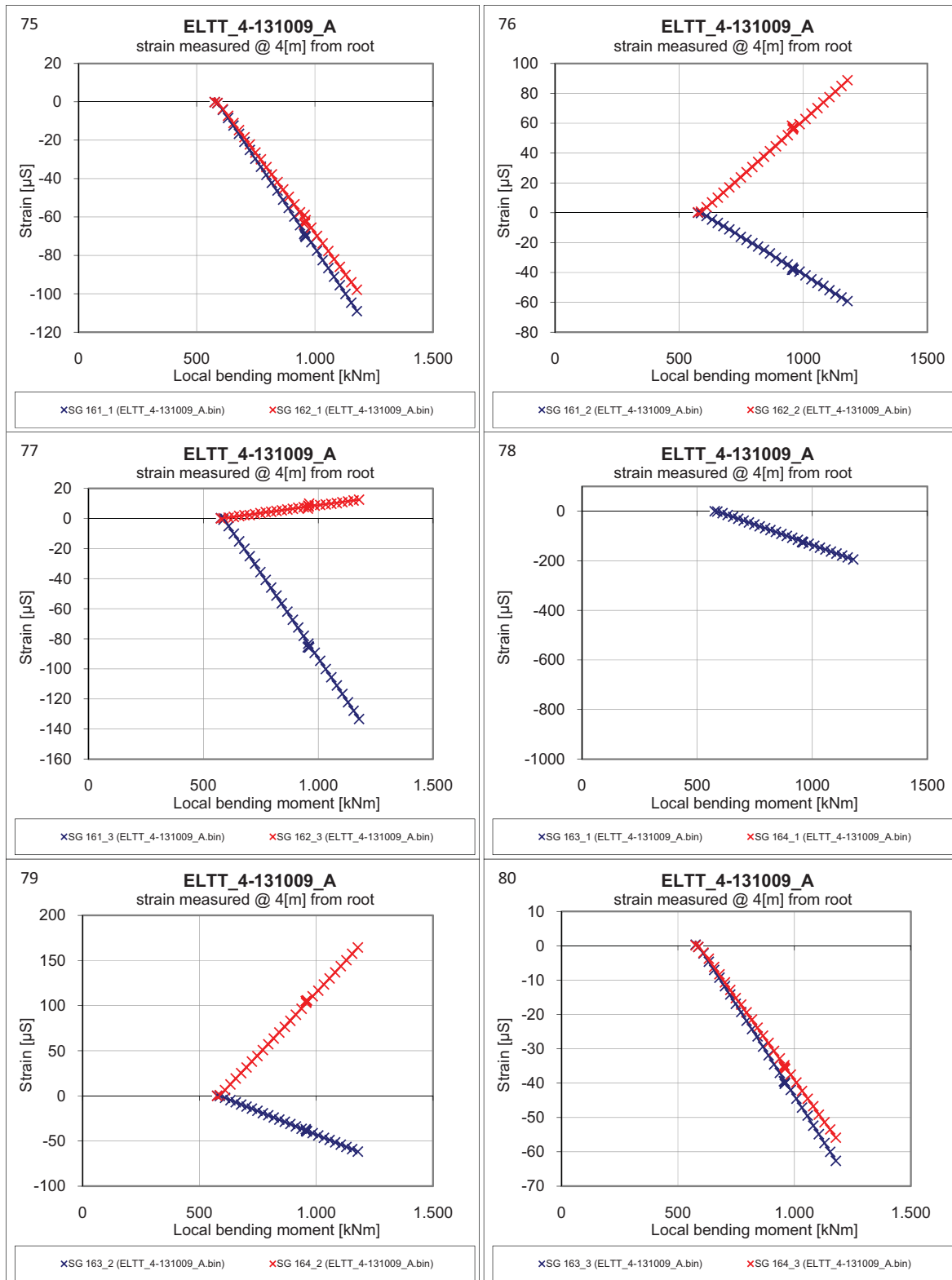
B1 Measurement of pull with trailing edge panel reinforcement at 60% Risø load (ELTT_131009_A)

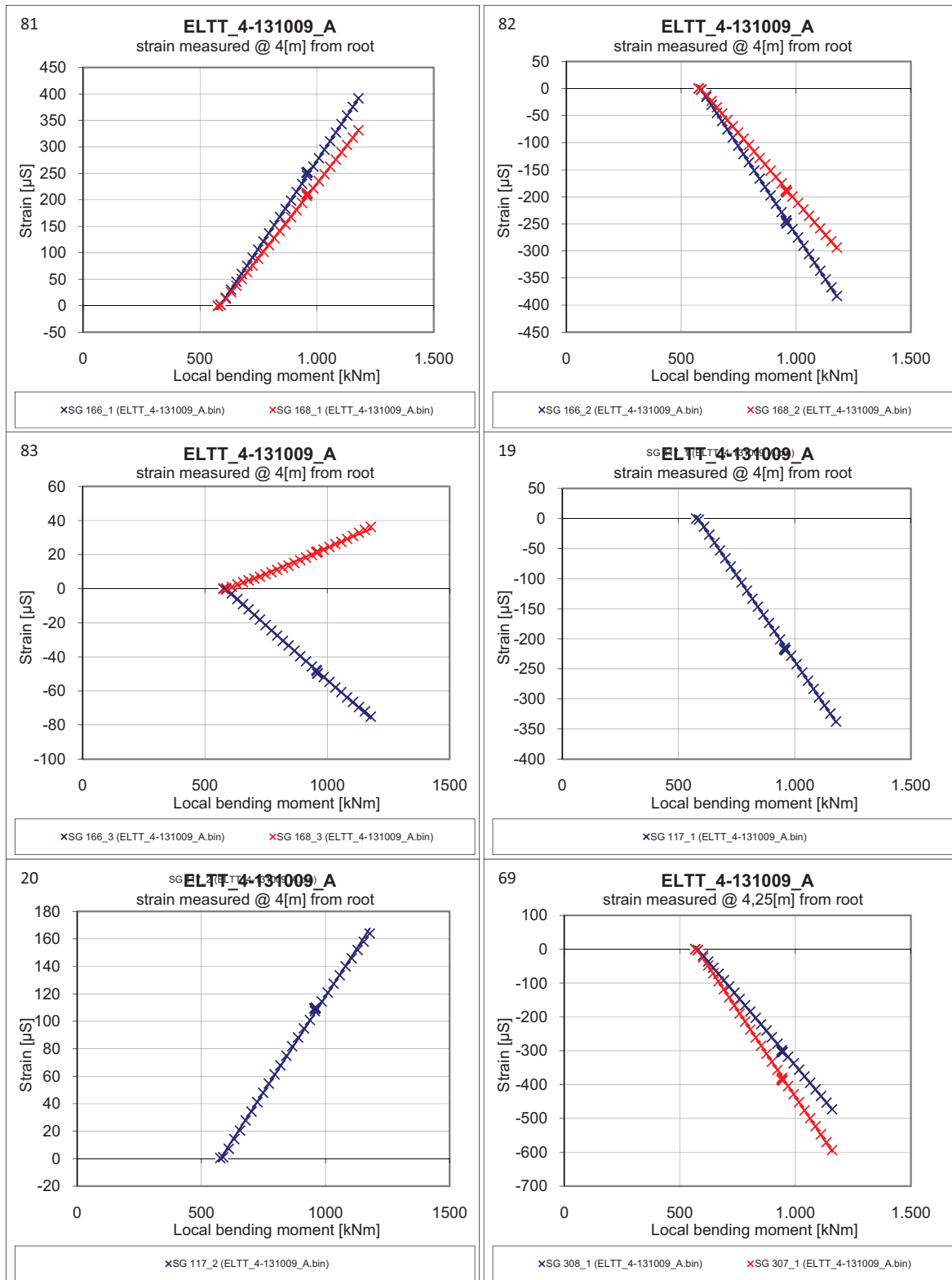
B.1.a Measured strain vs. bending moment

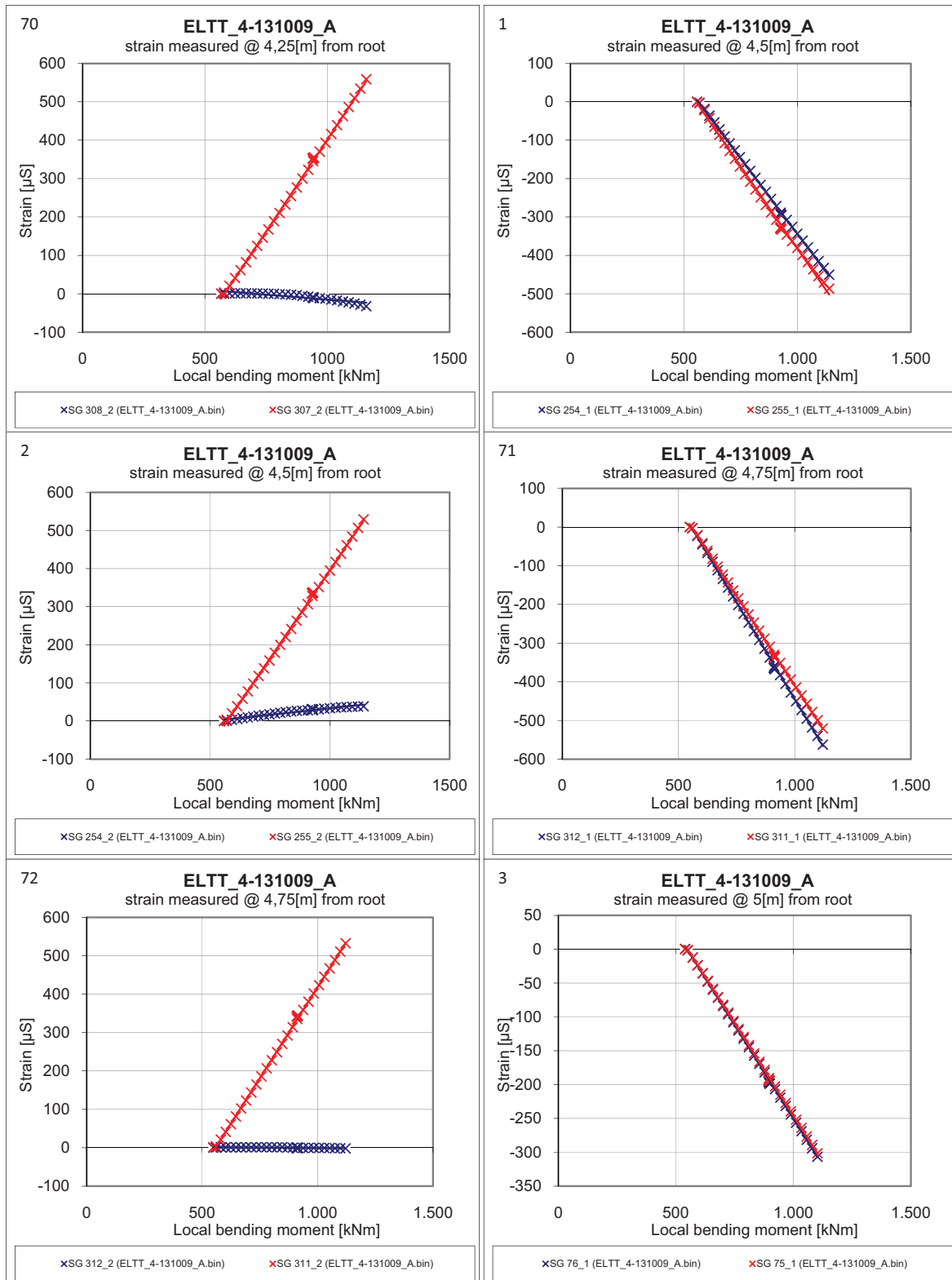
Measurements obtained from strain gauges in:
Main section in Test ELTT_4-131009_A

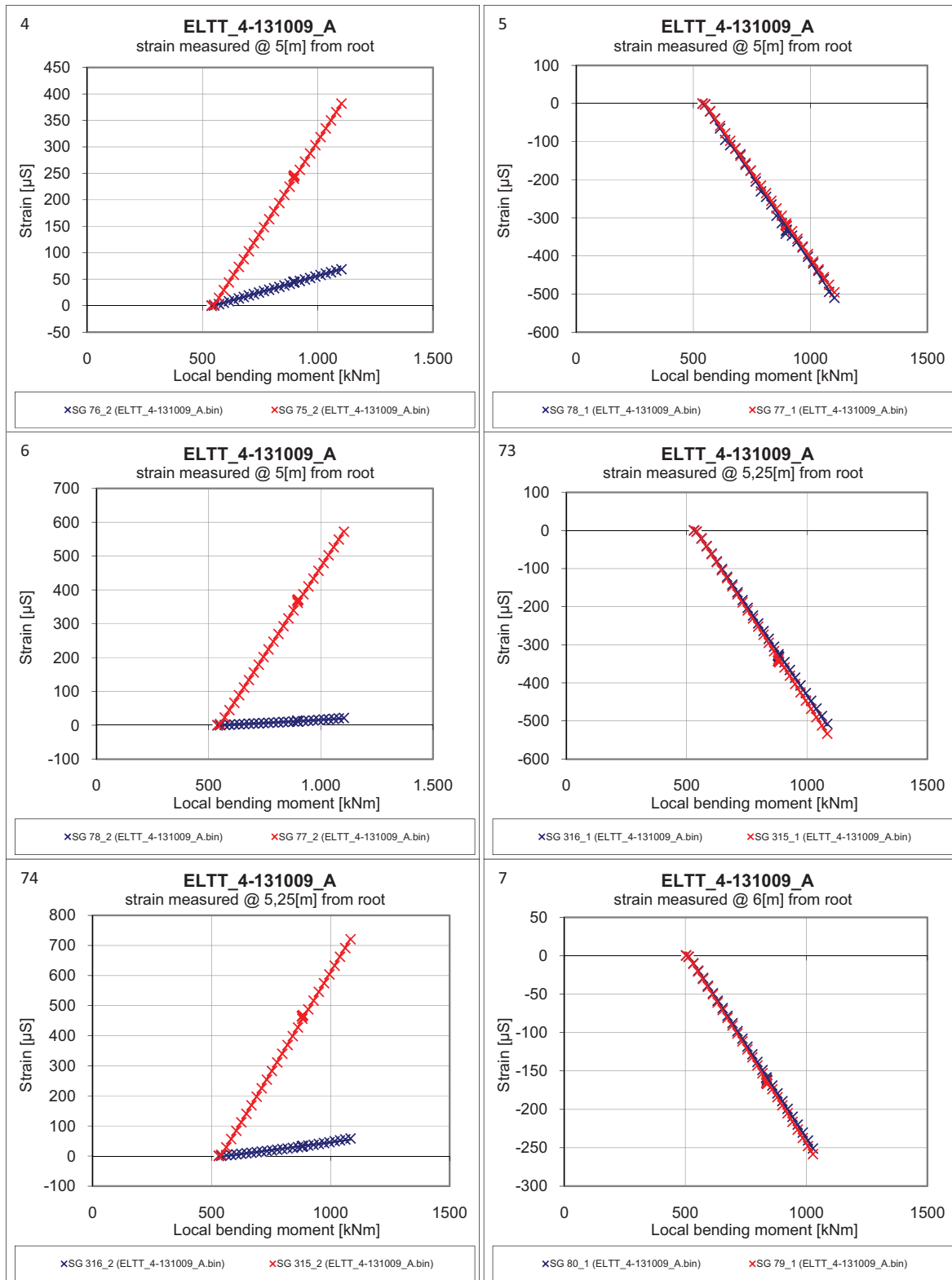


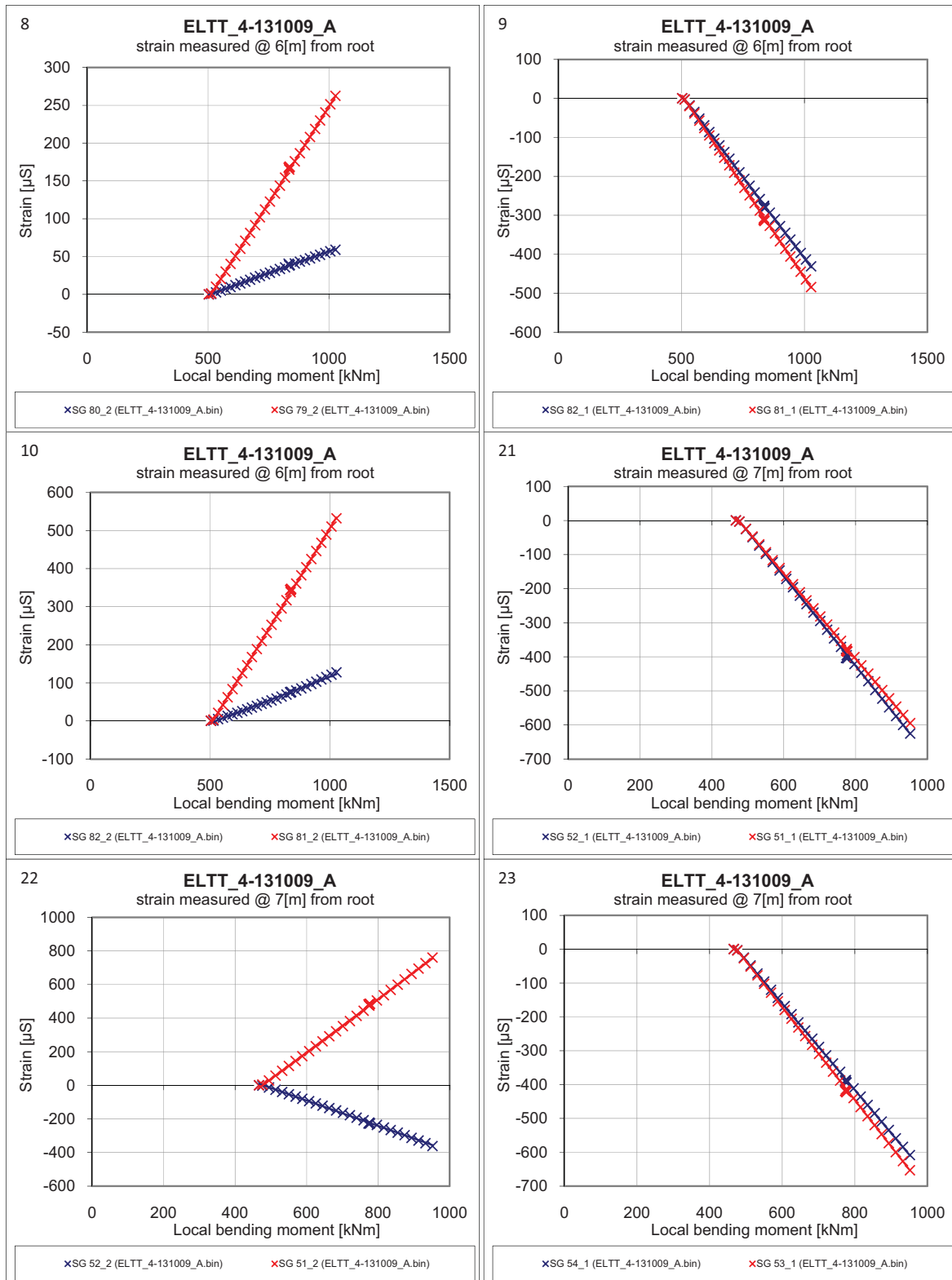


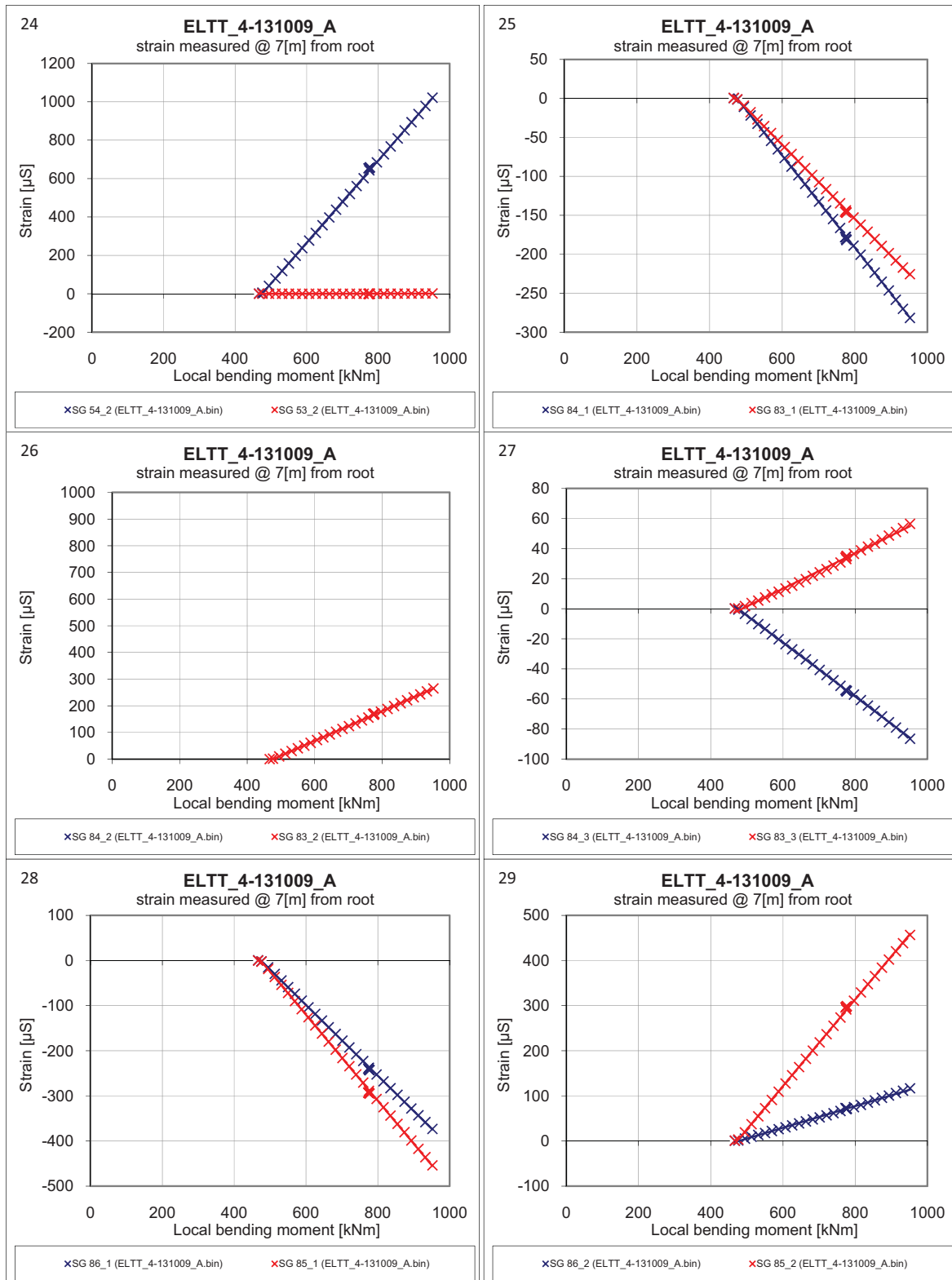


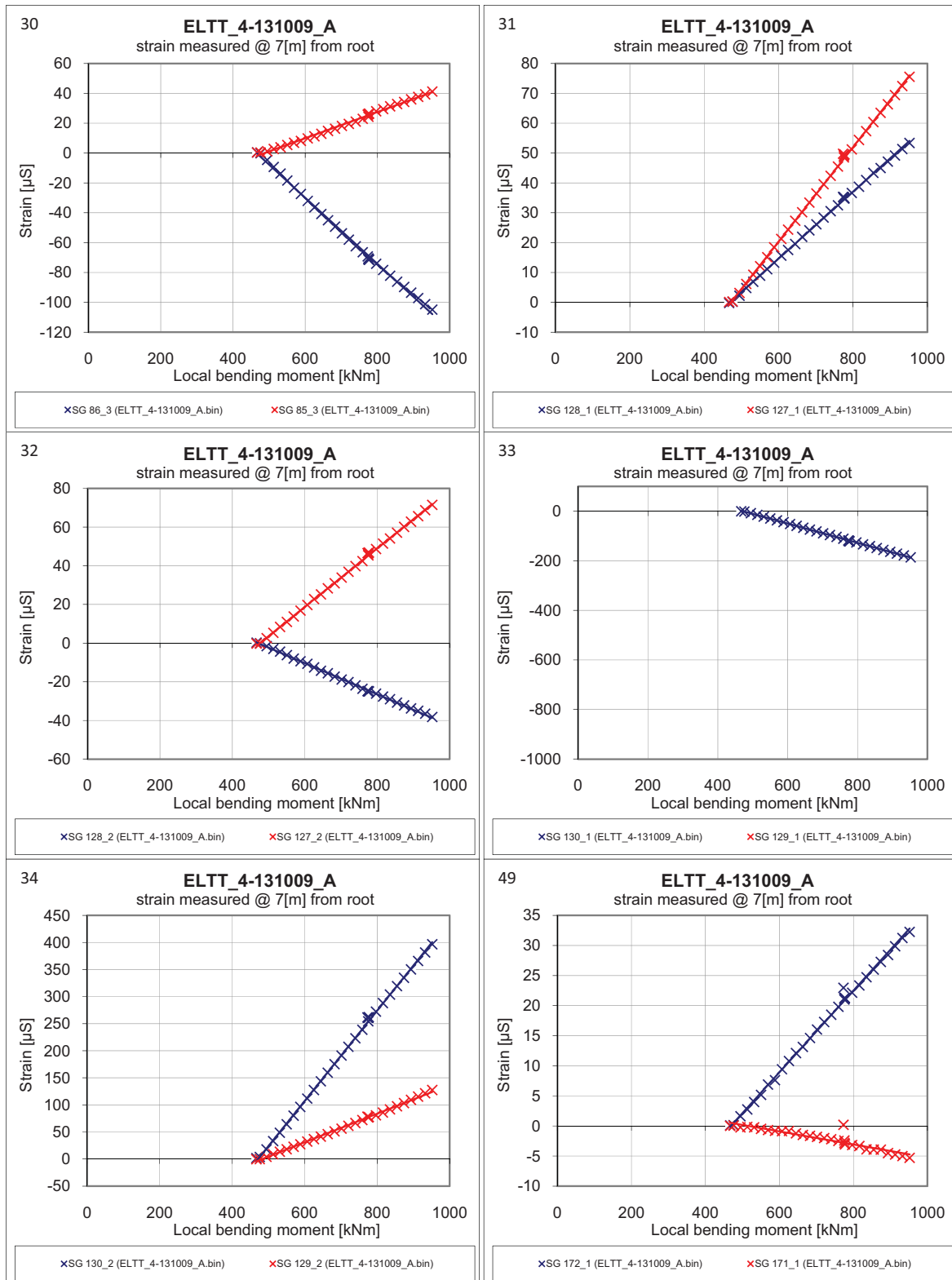


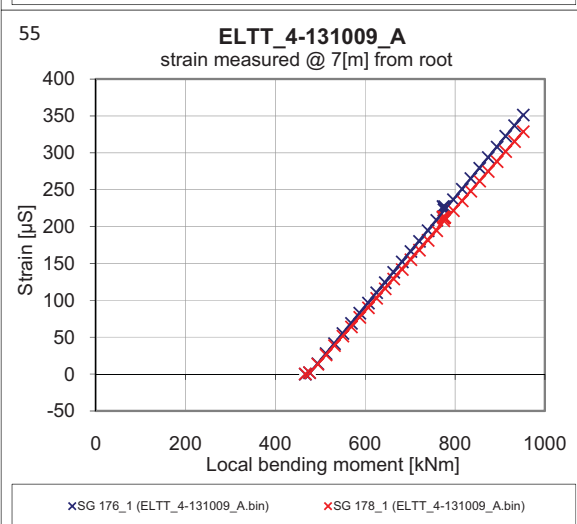
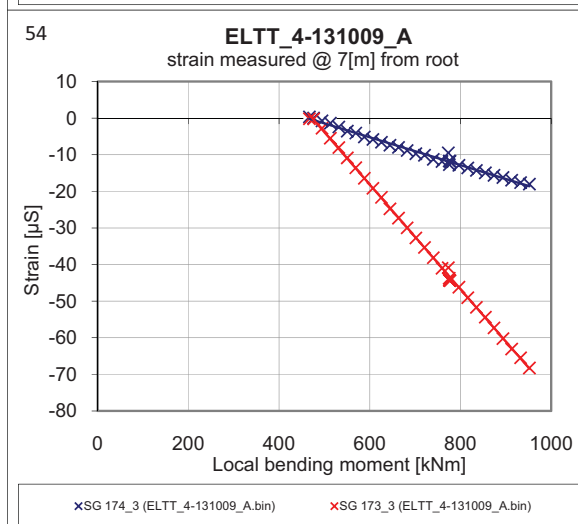
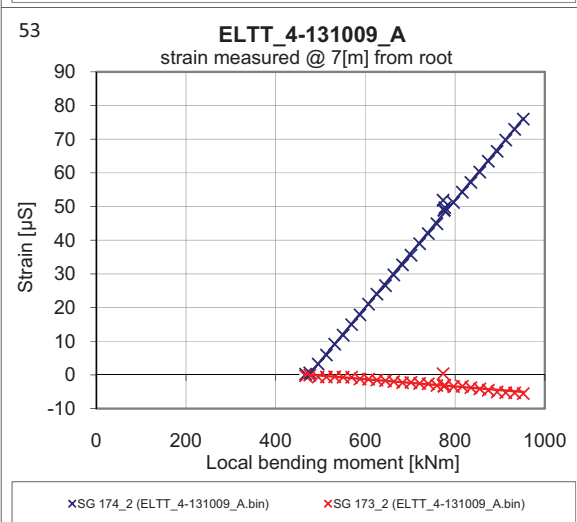
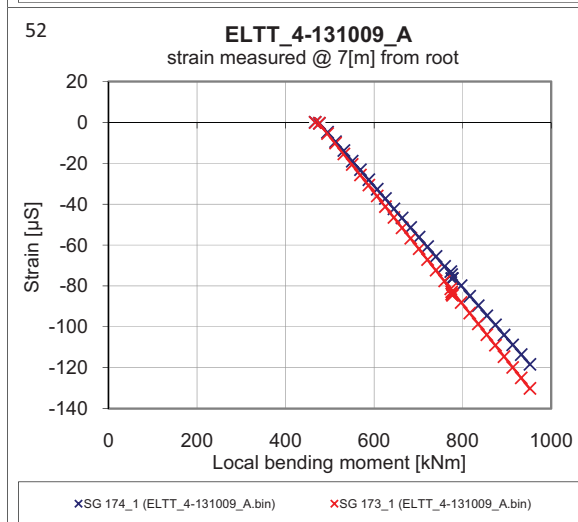
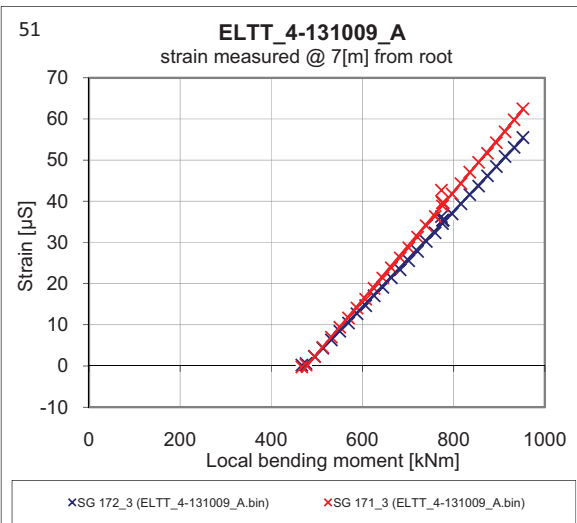
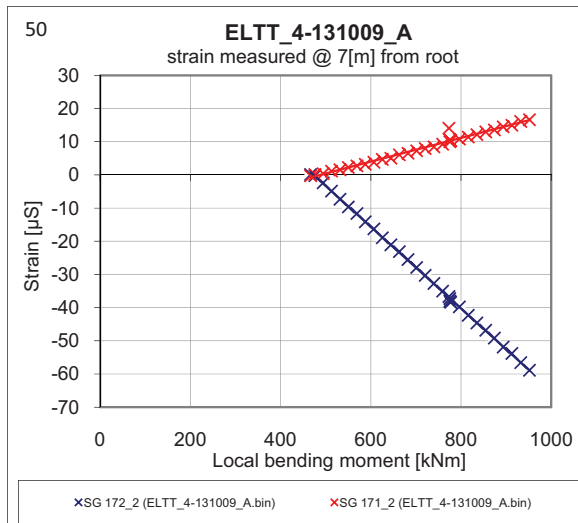


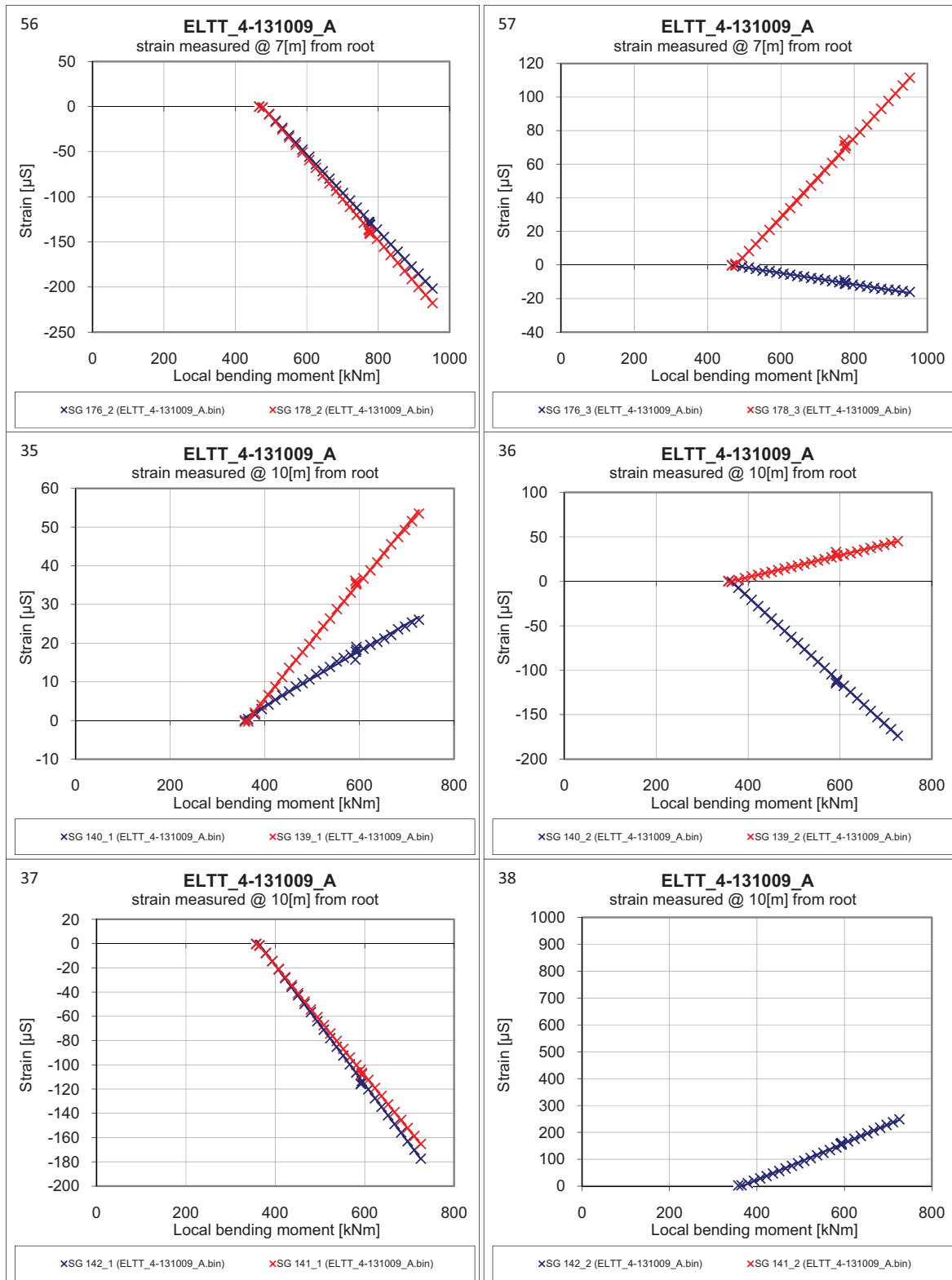


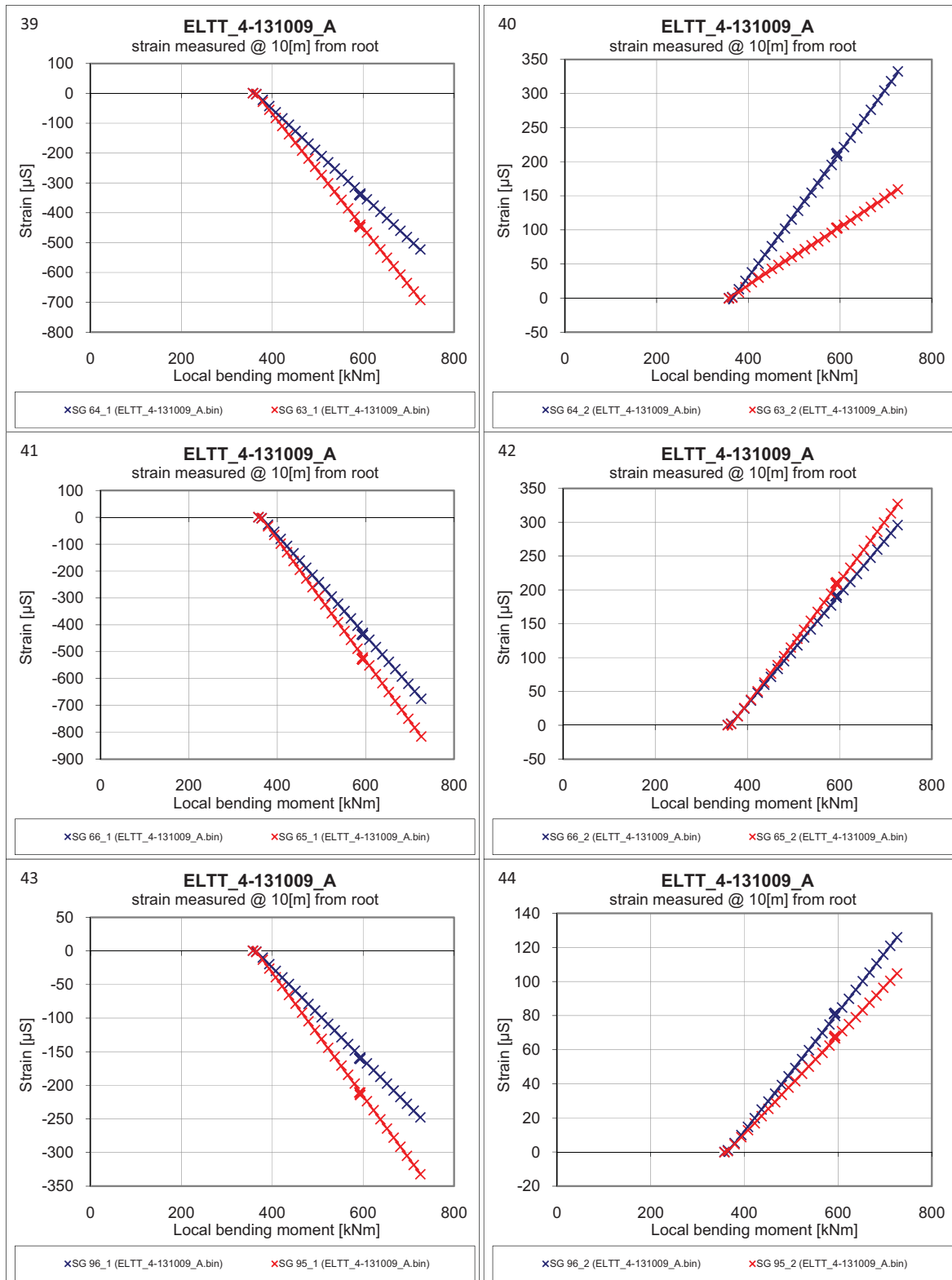


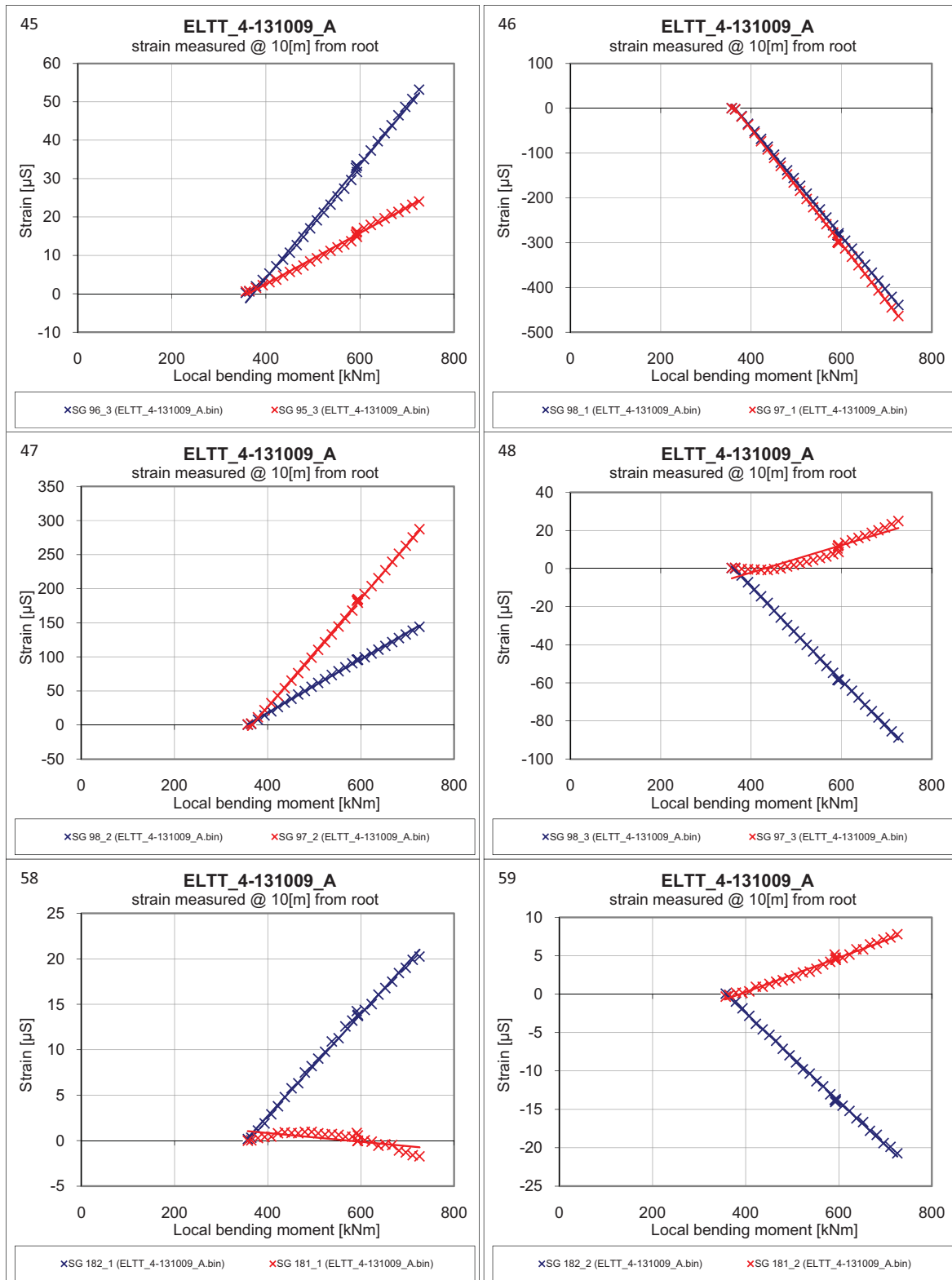


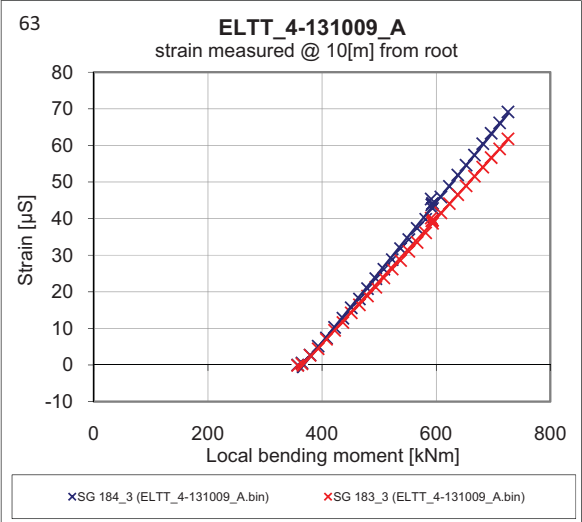
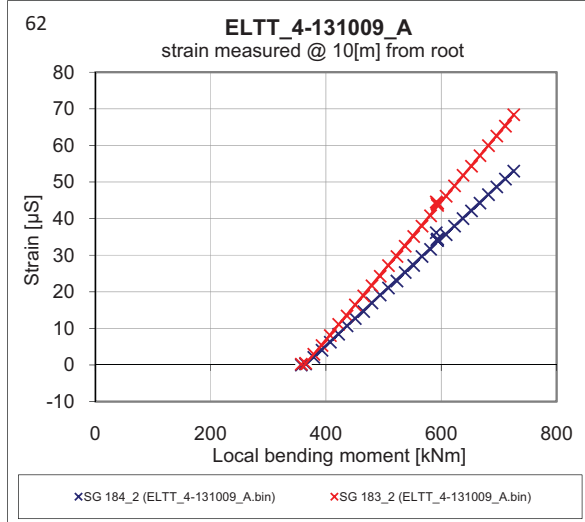
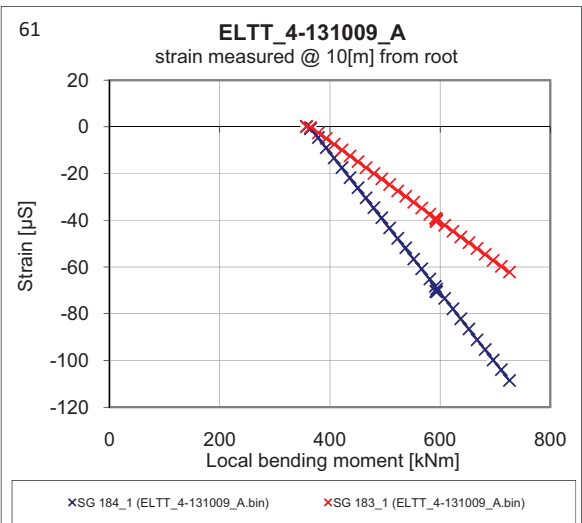
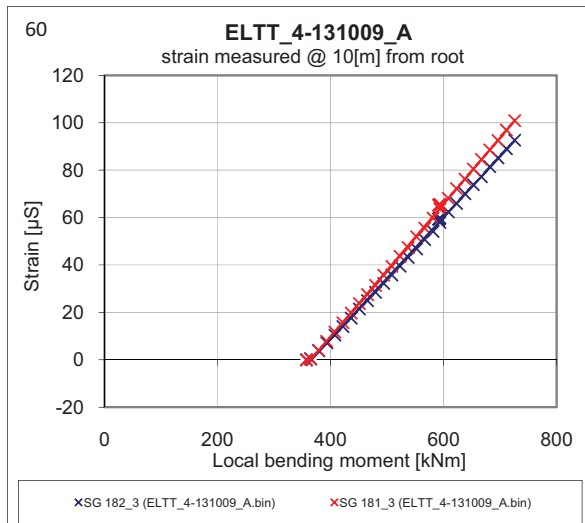


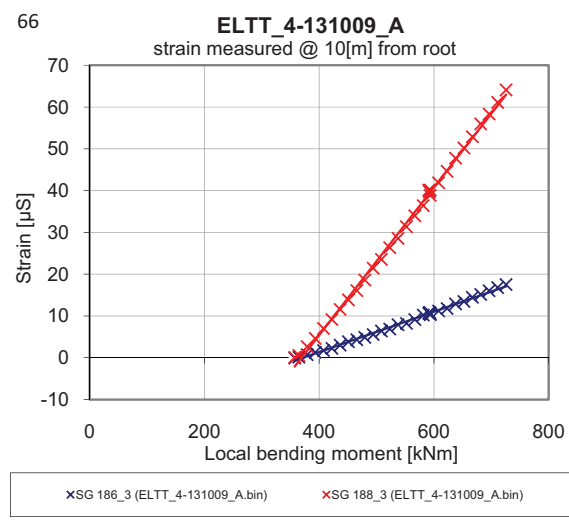
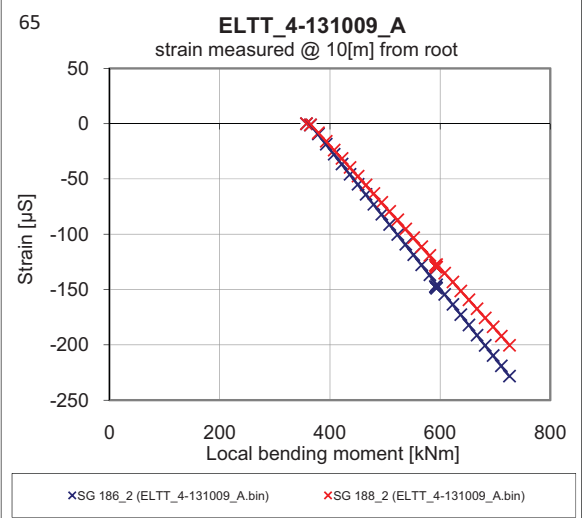
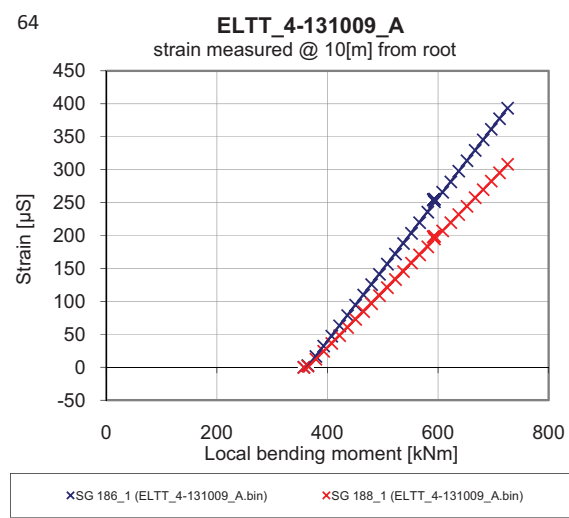






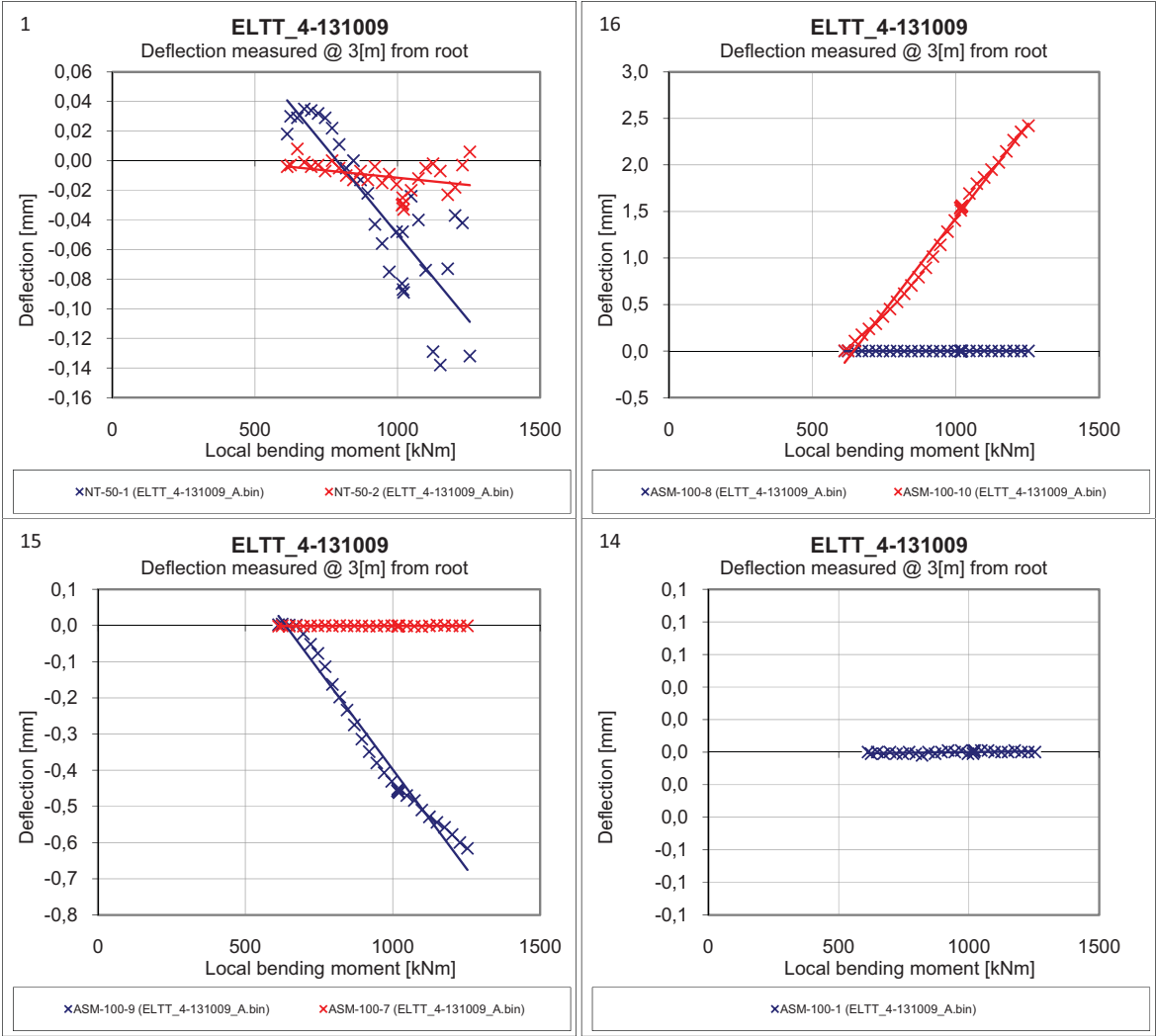


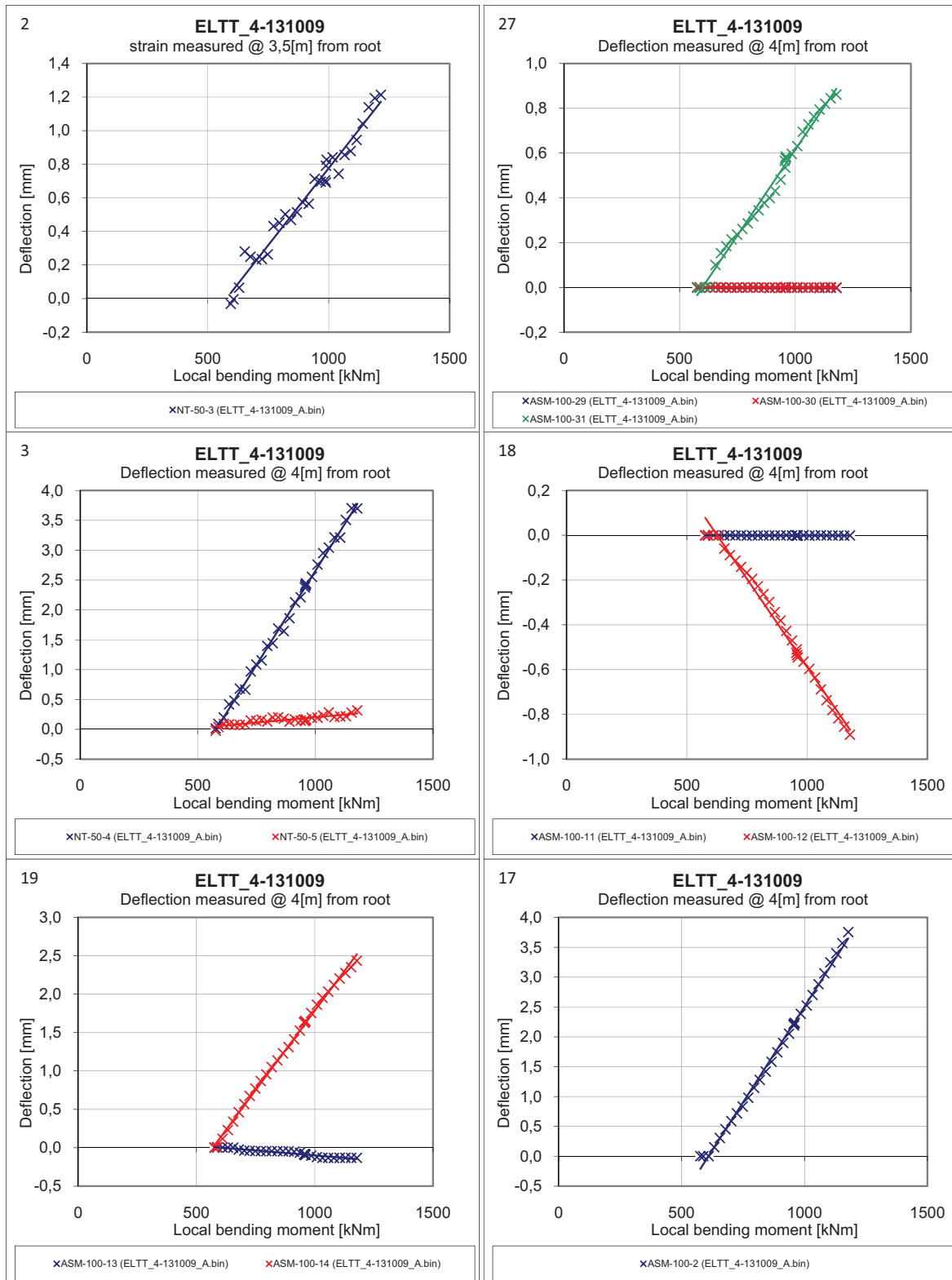


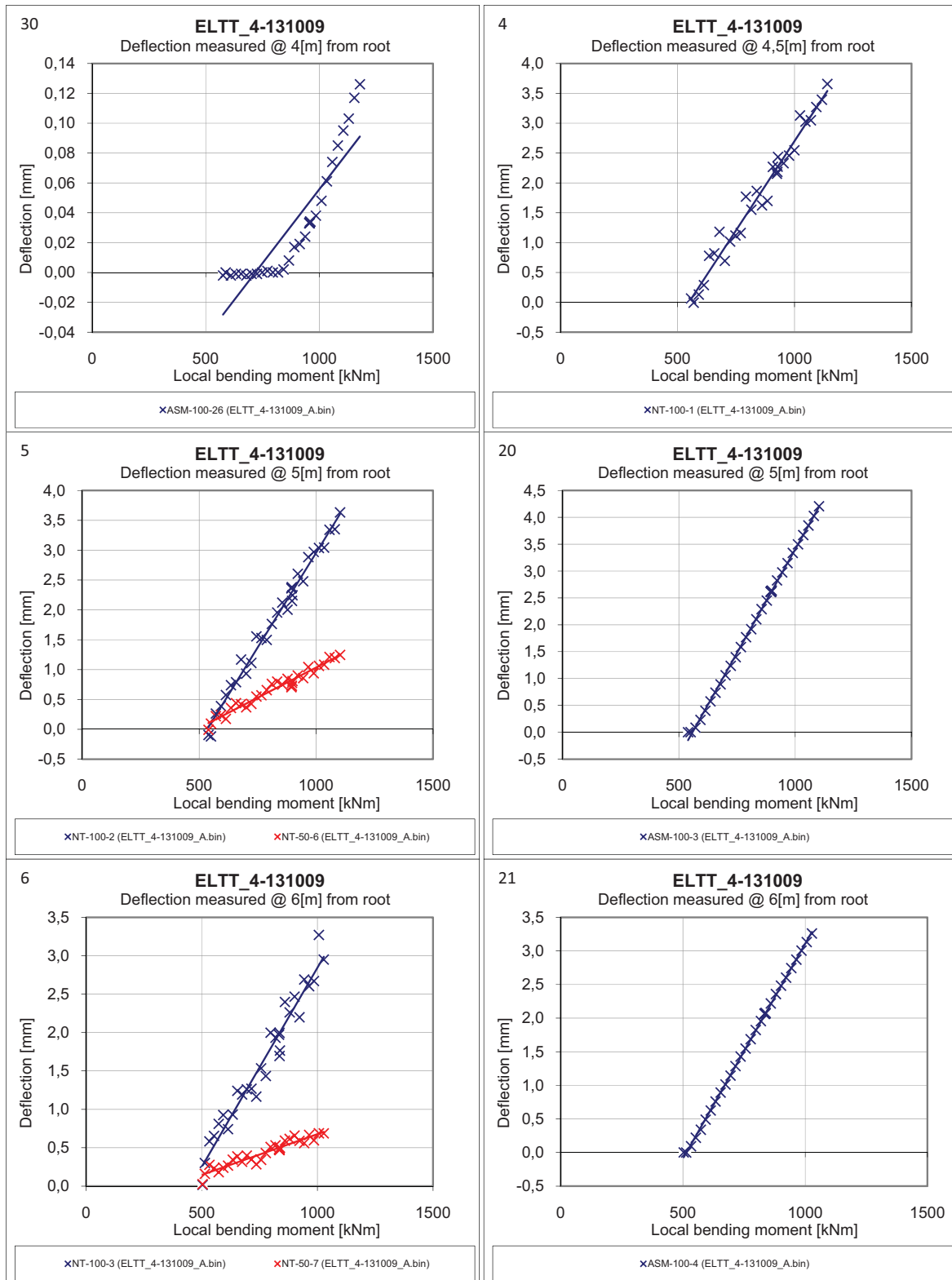


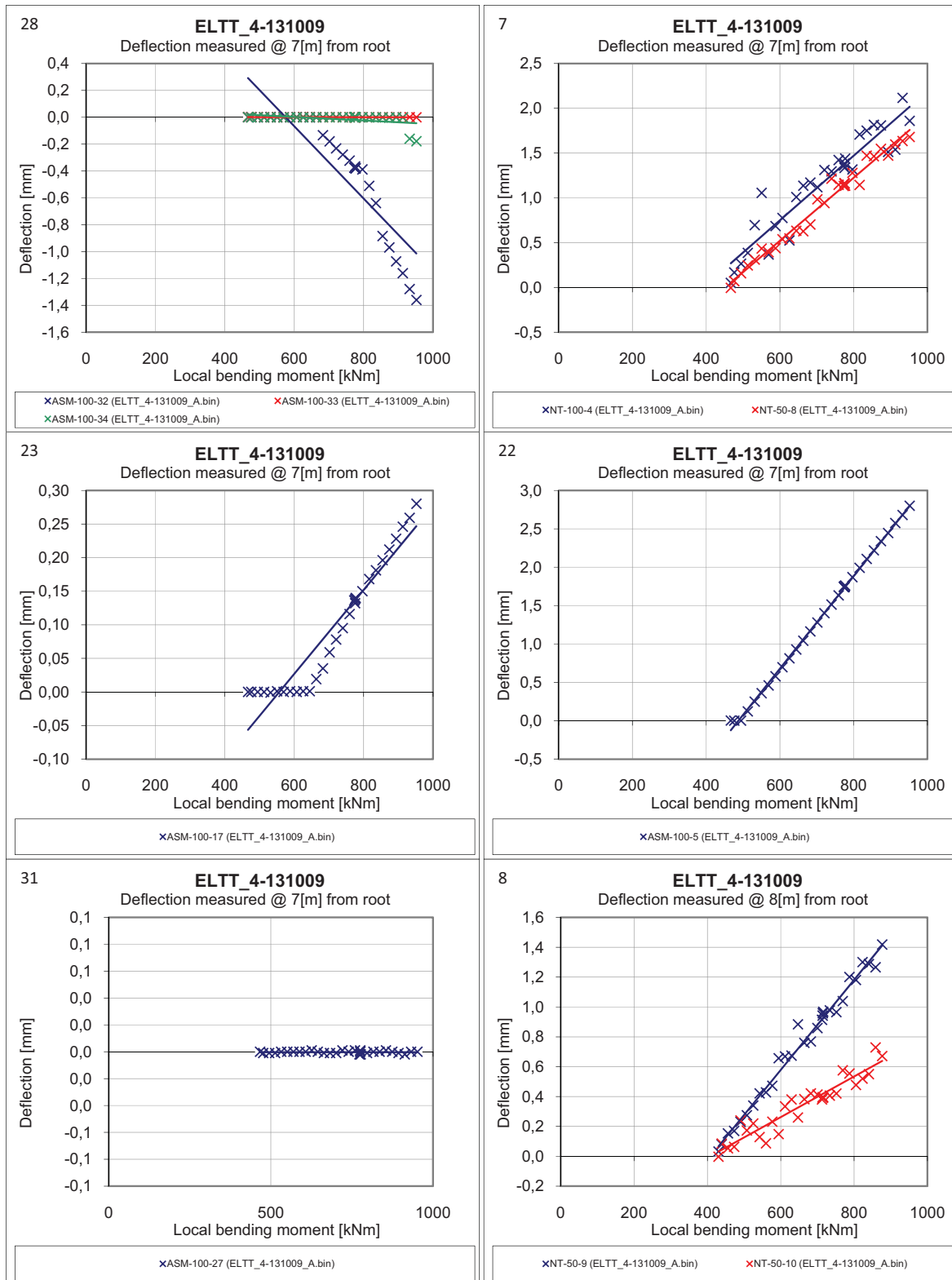
B.1.b The deflections measurements vs. local bending moment

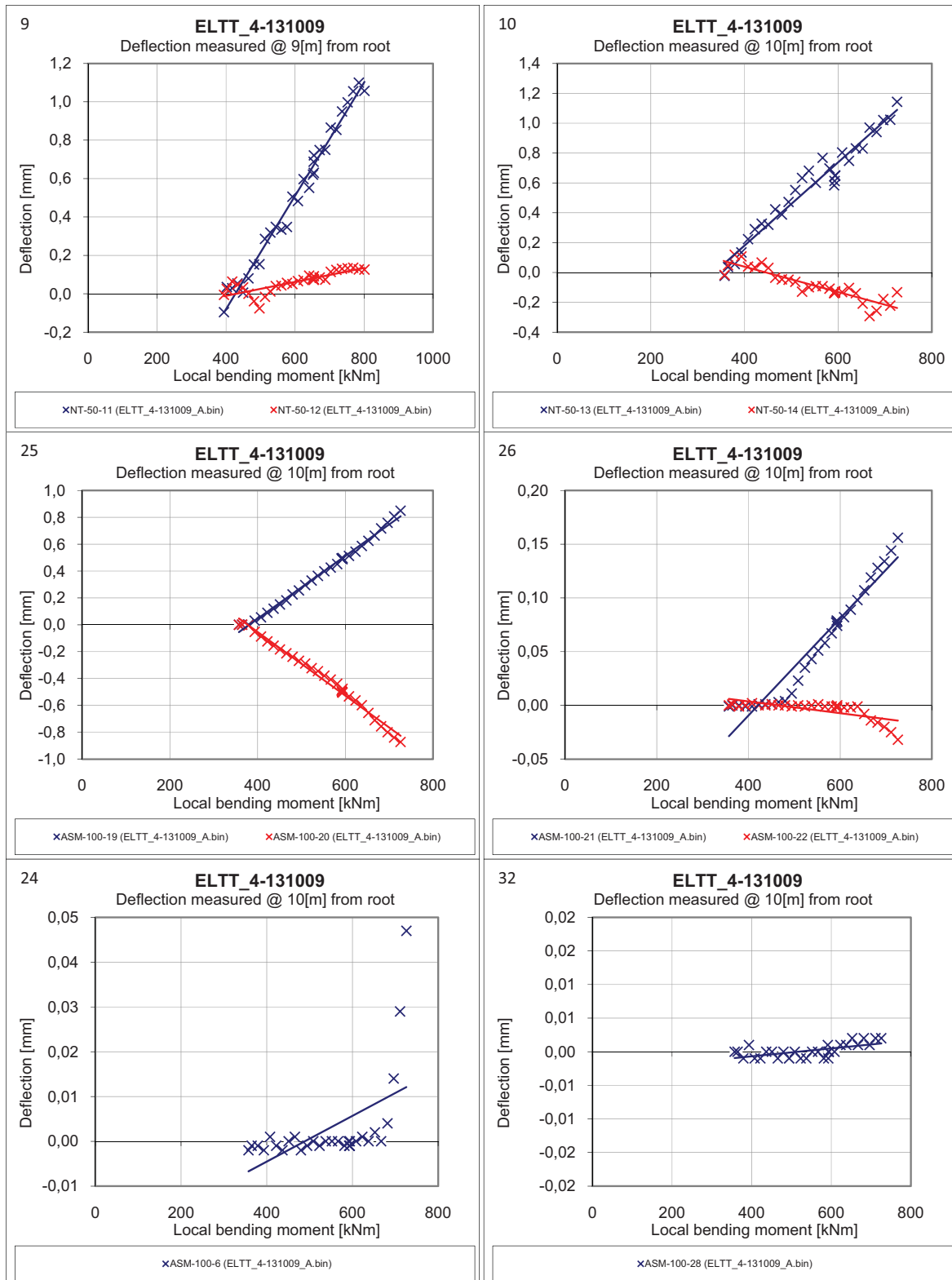
Deflections measured in test **ELTT_4-131009_A**

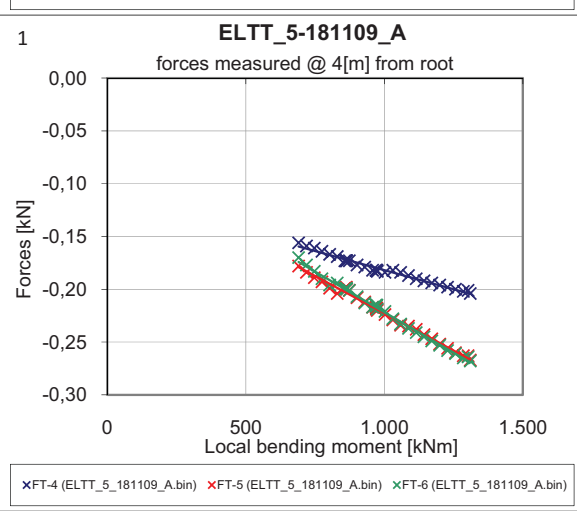
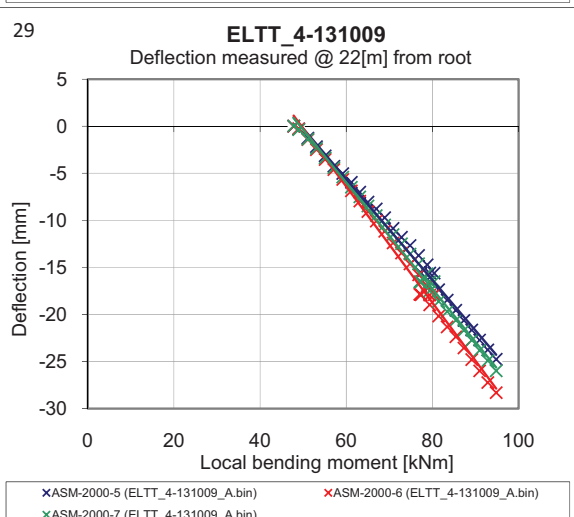
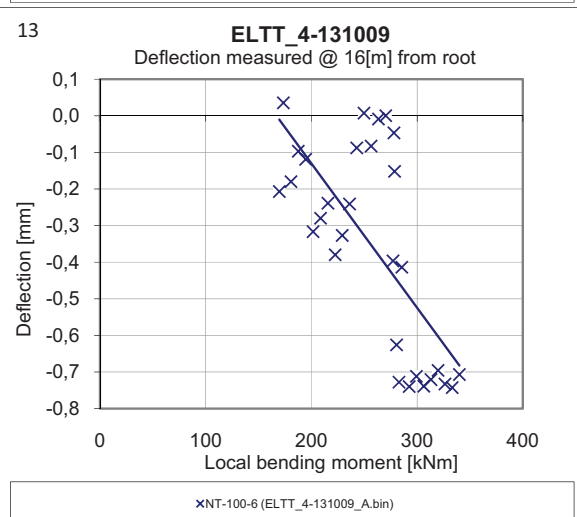
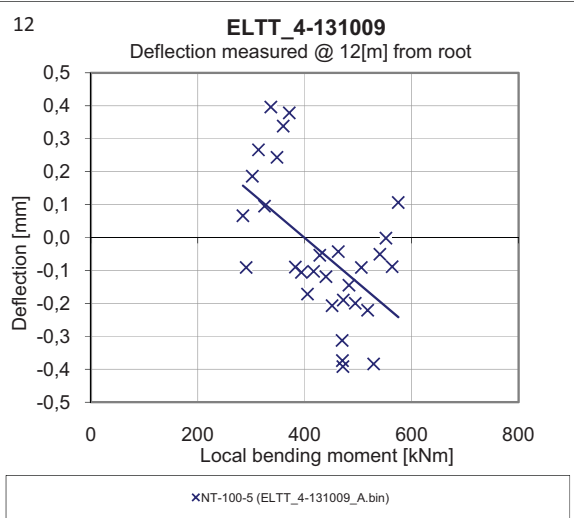
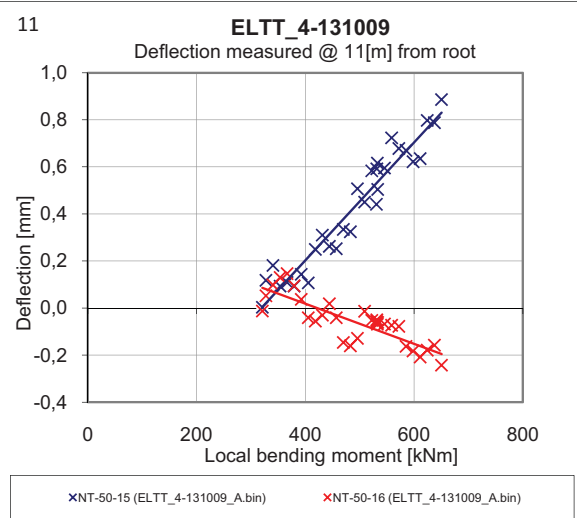






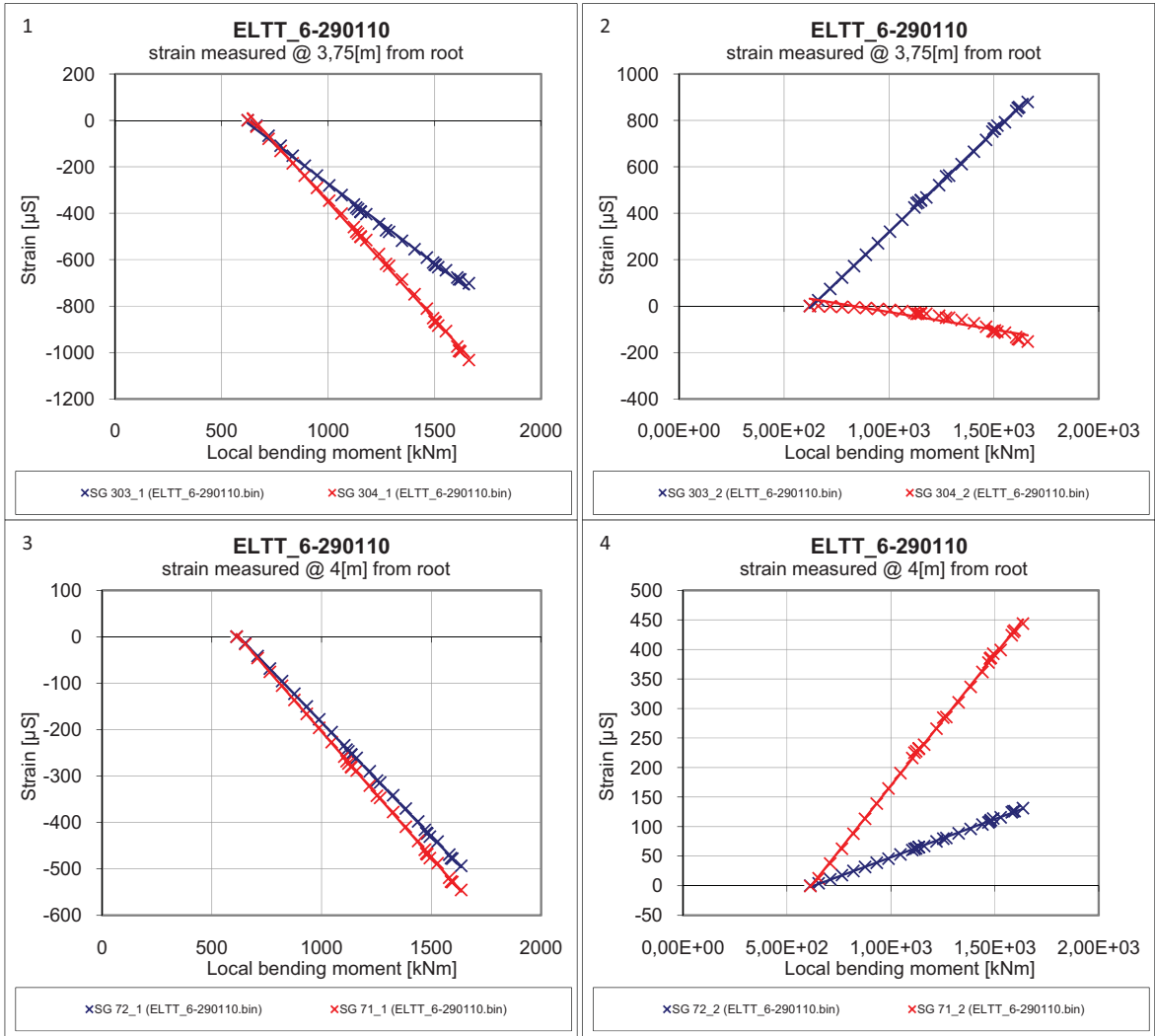


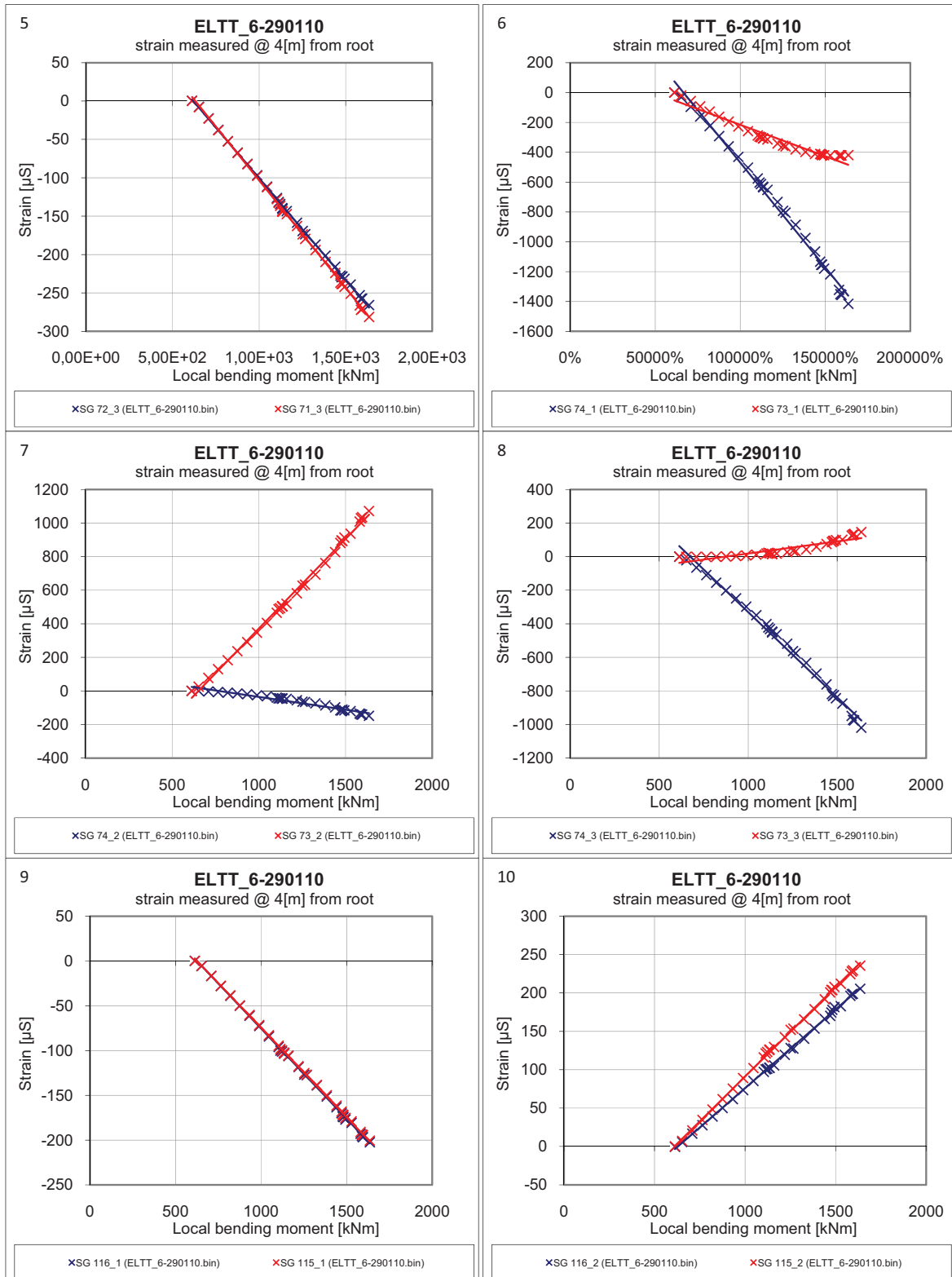


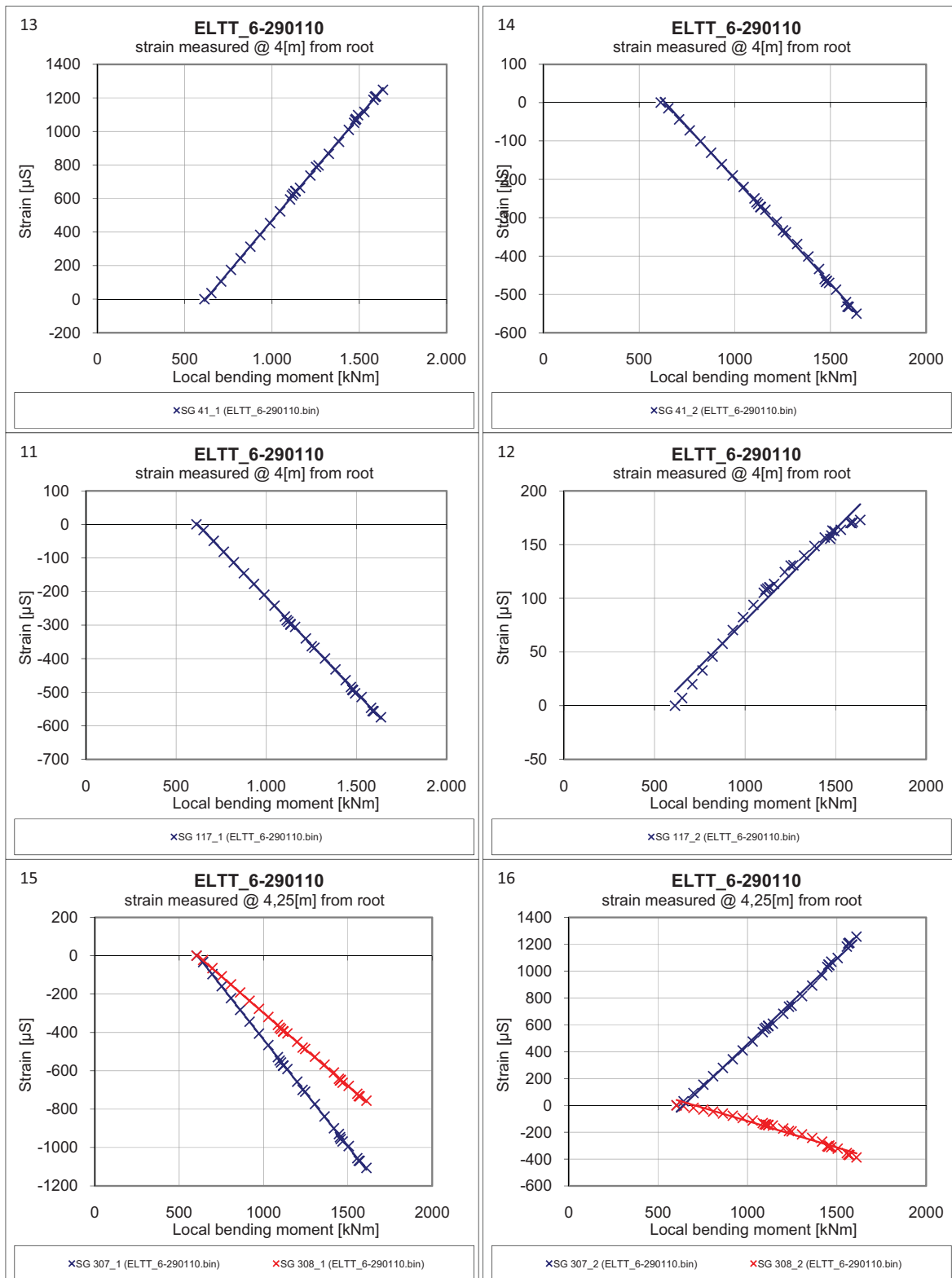


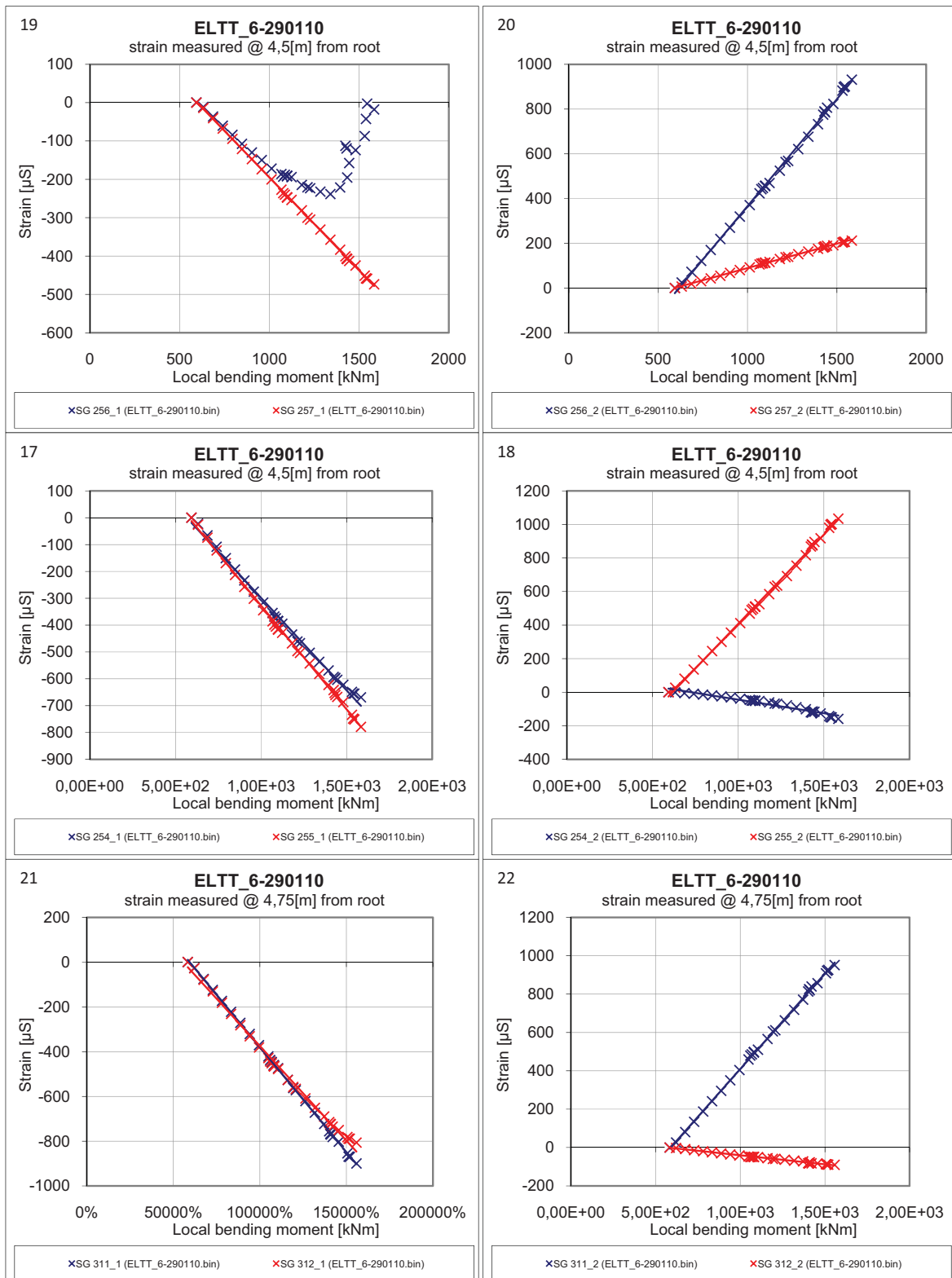
B2 Strain measurements of pull with trailing edge panel reinforcement at 80% Risø load

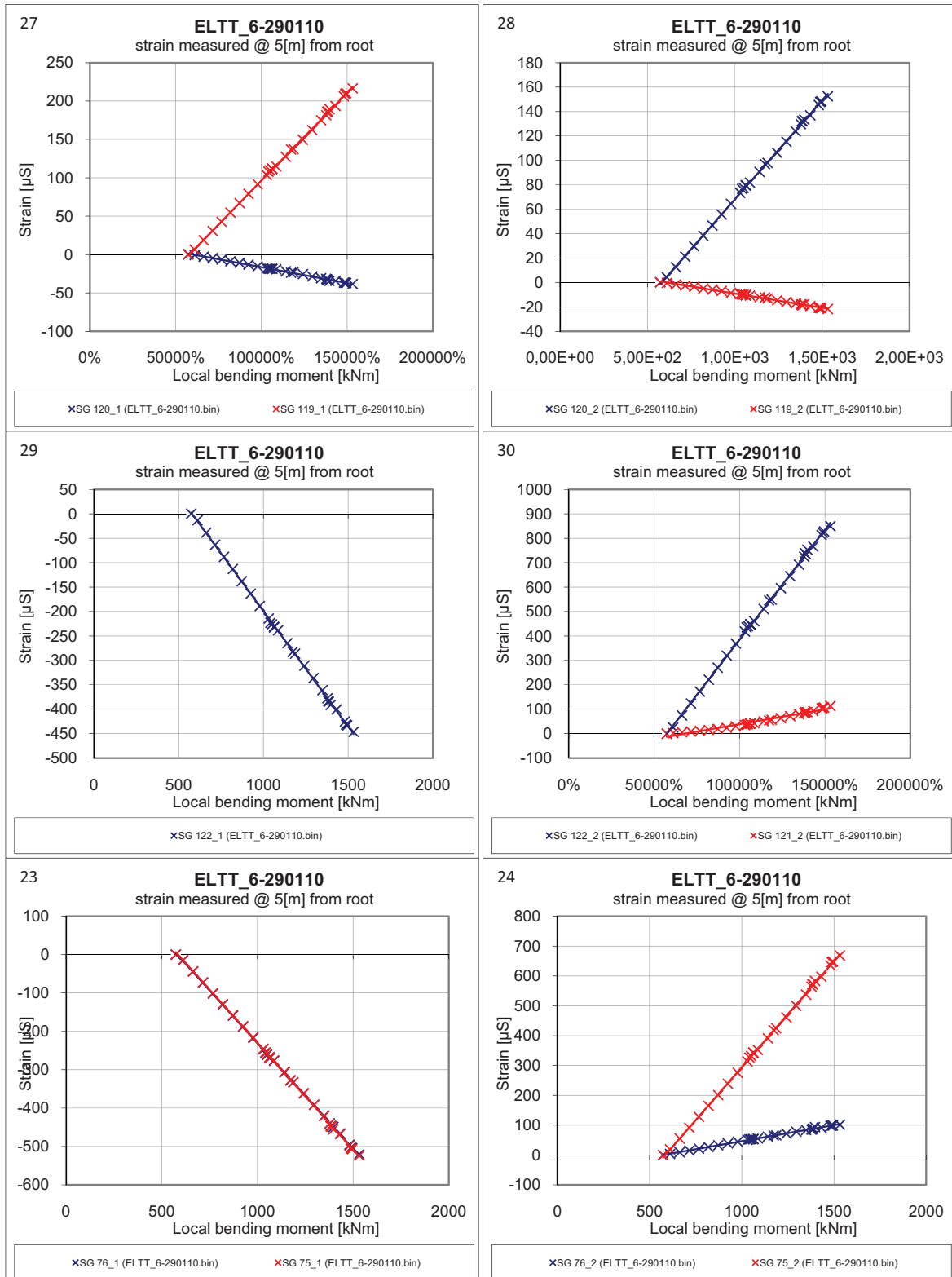
B2a ELLT_6_290110

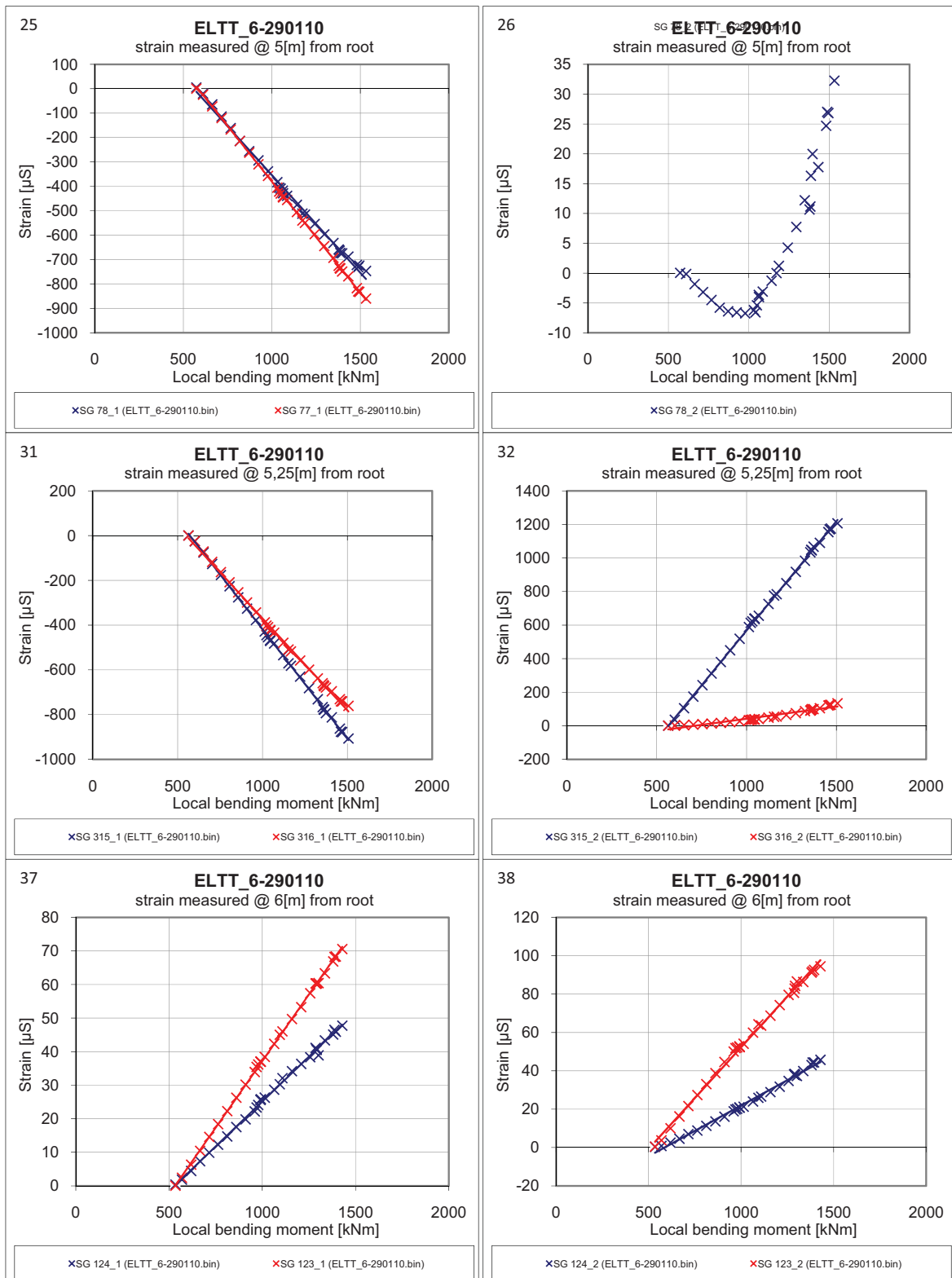


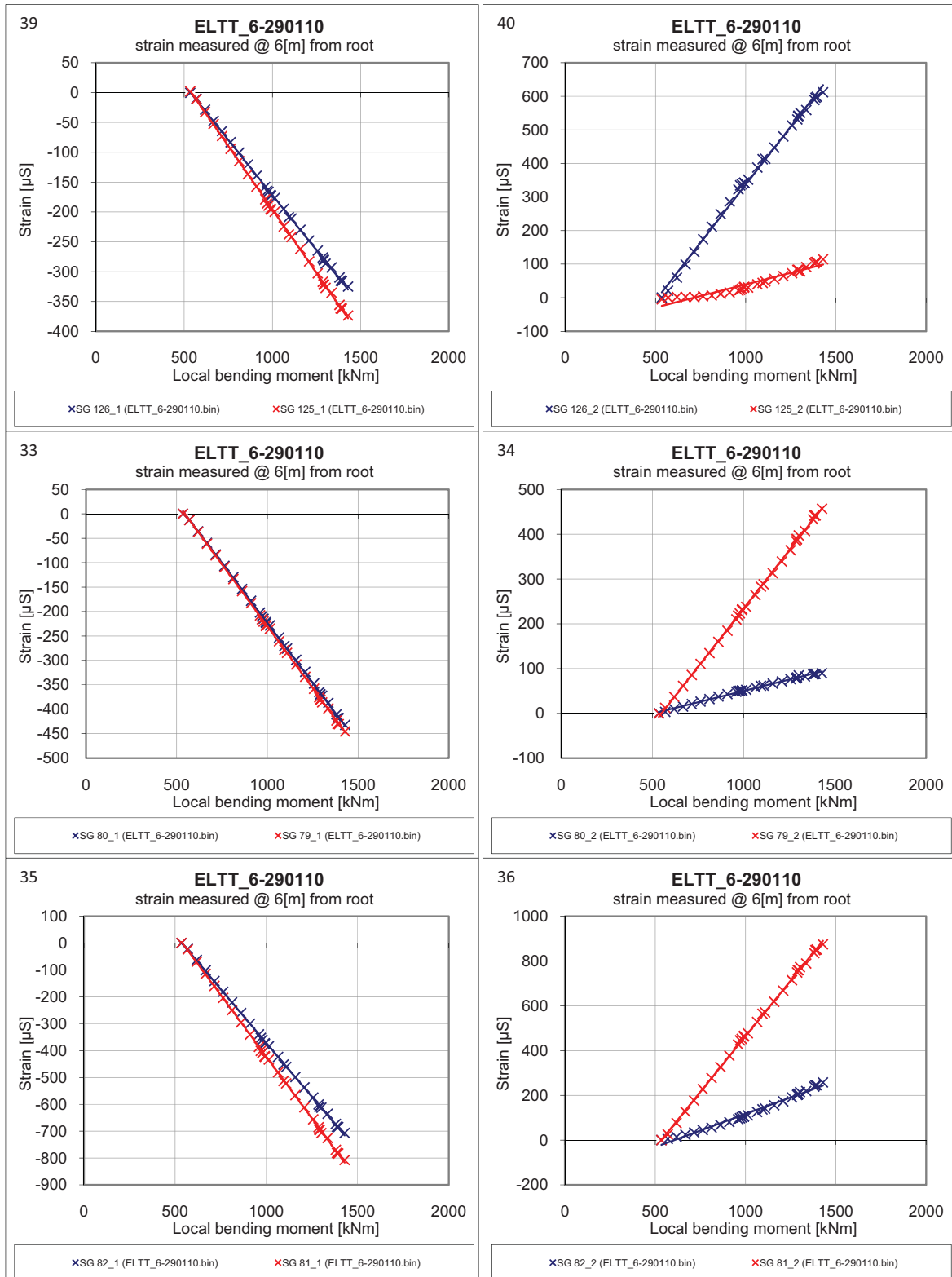


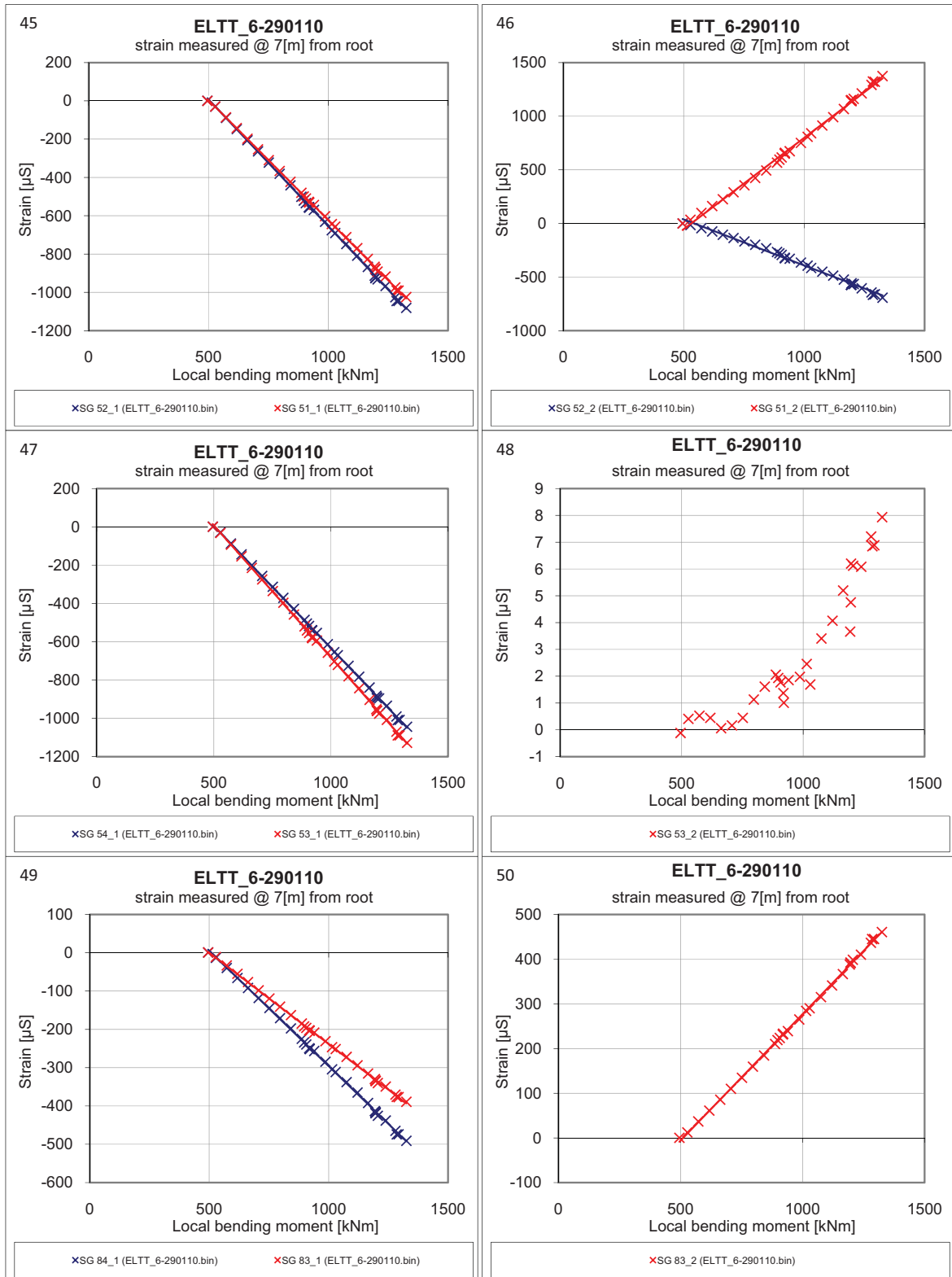


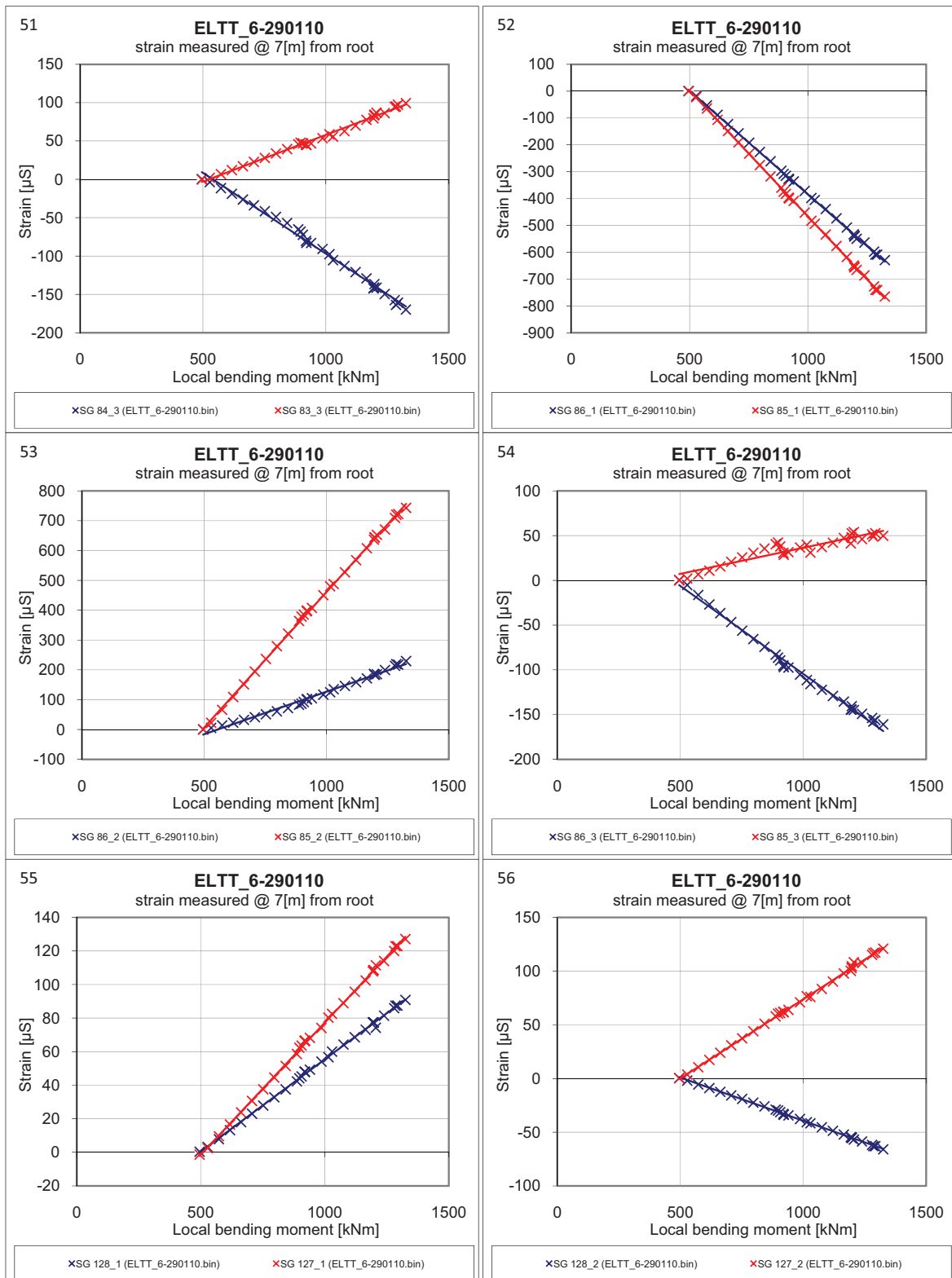


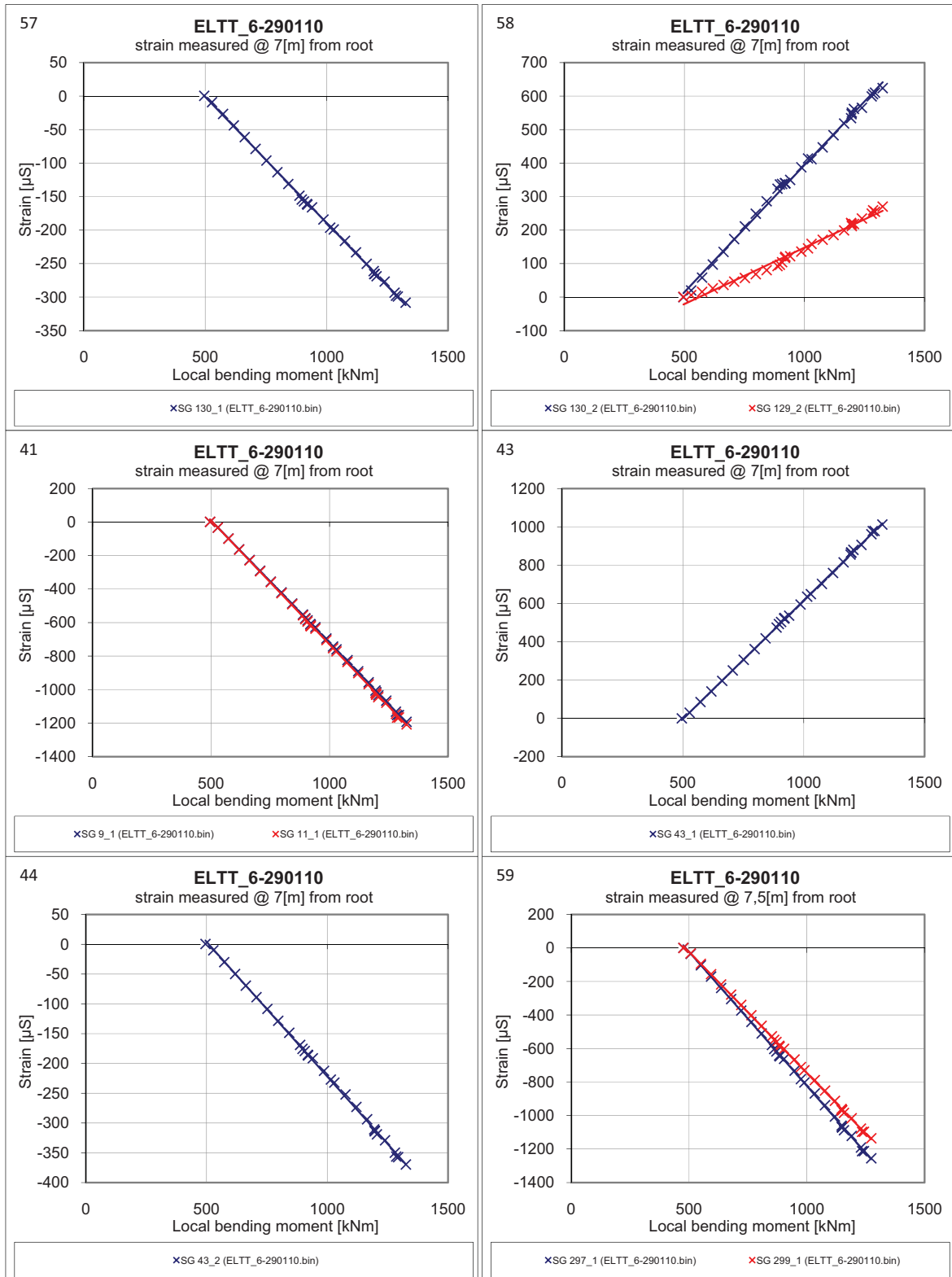


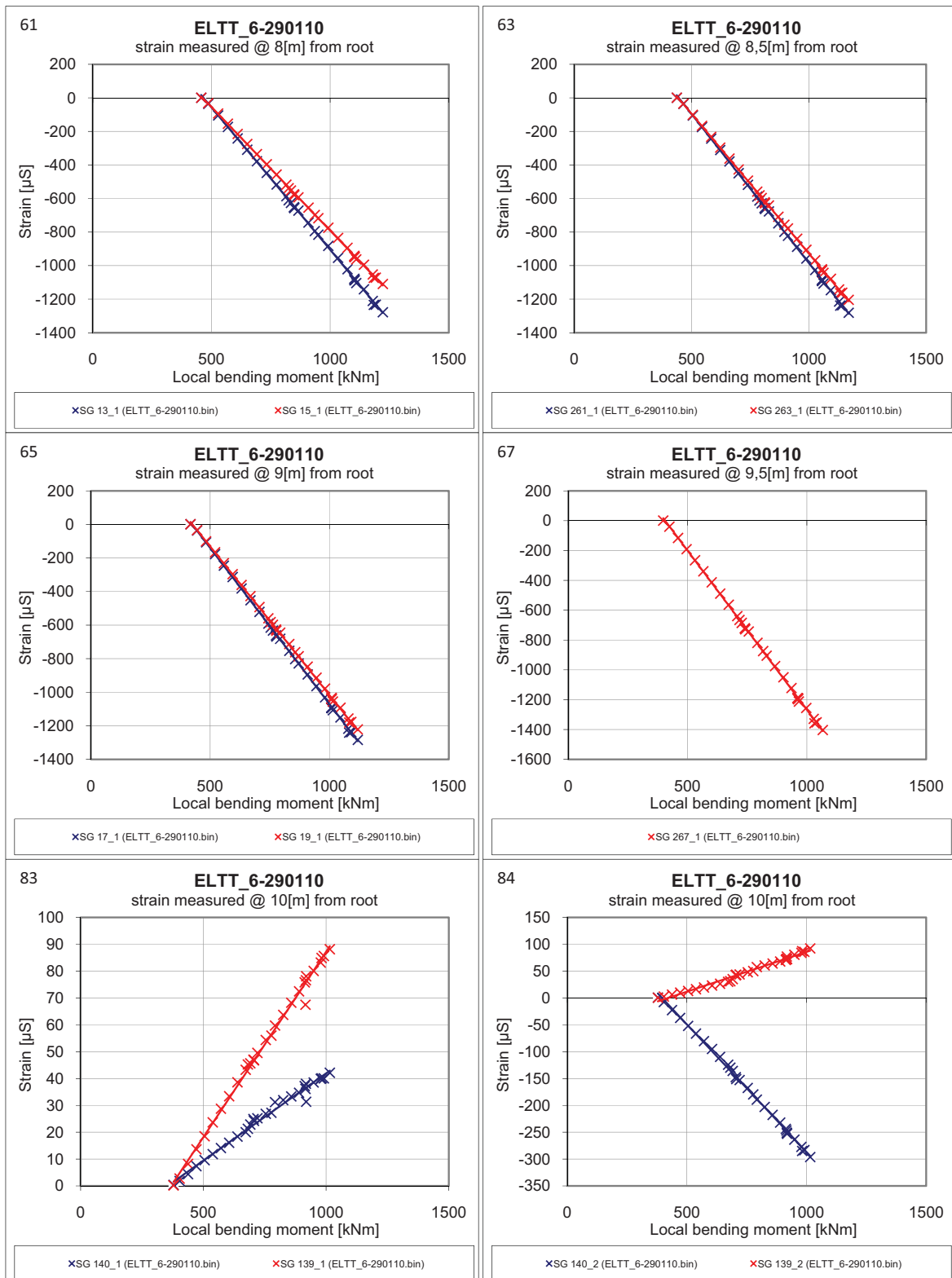


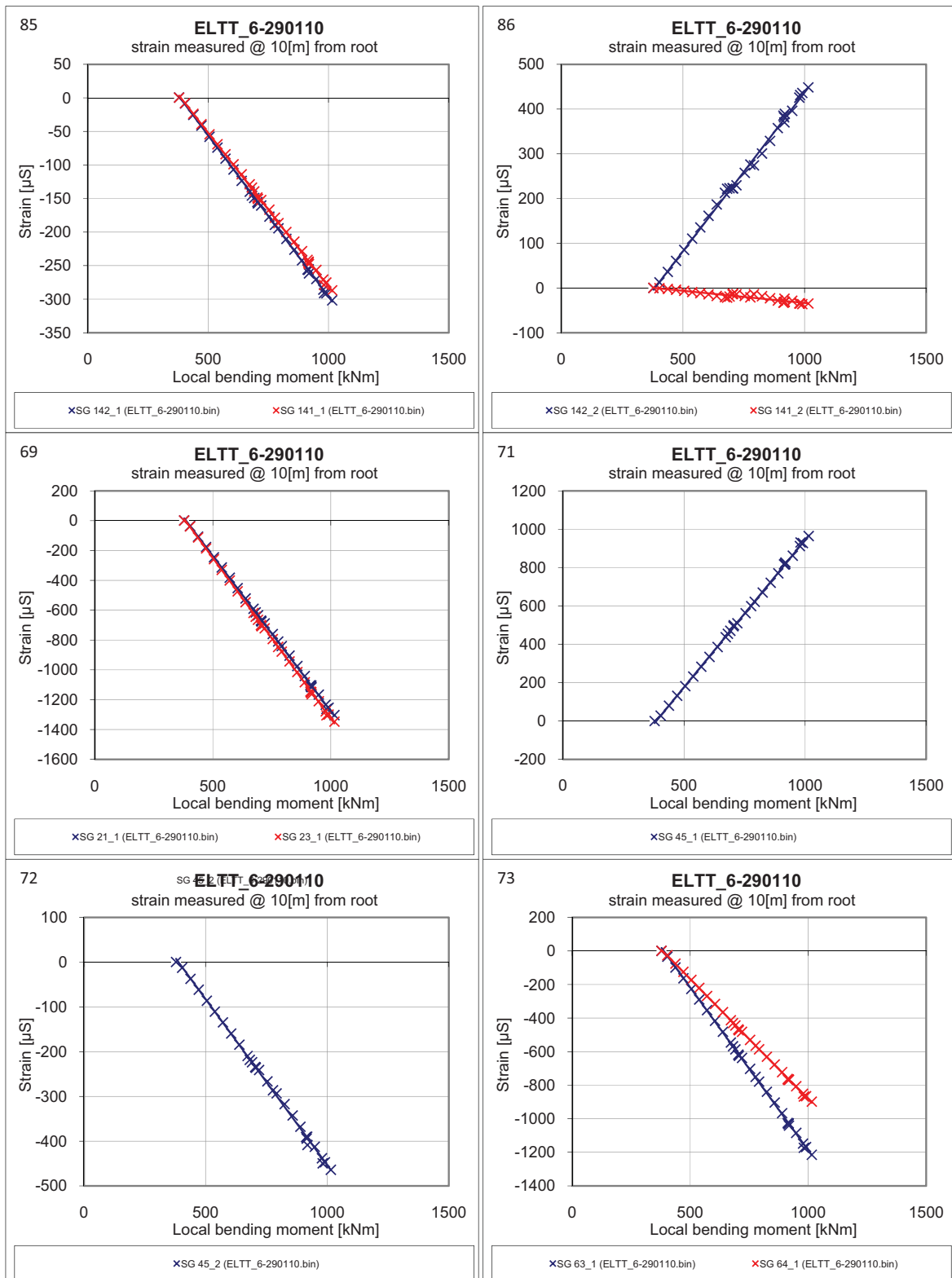


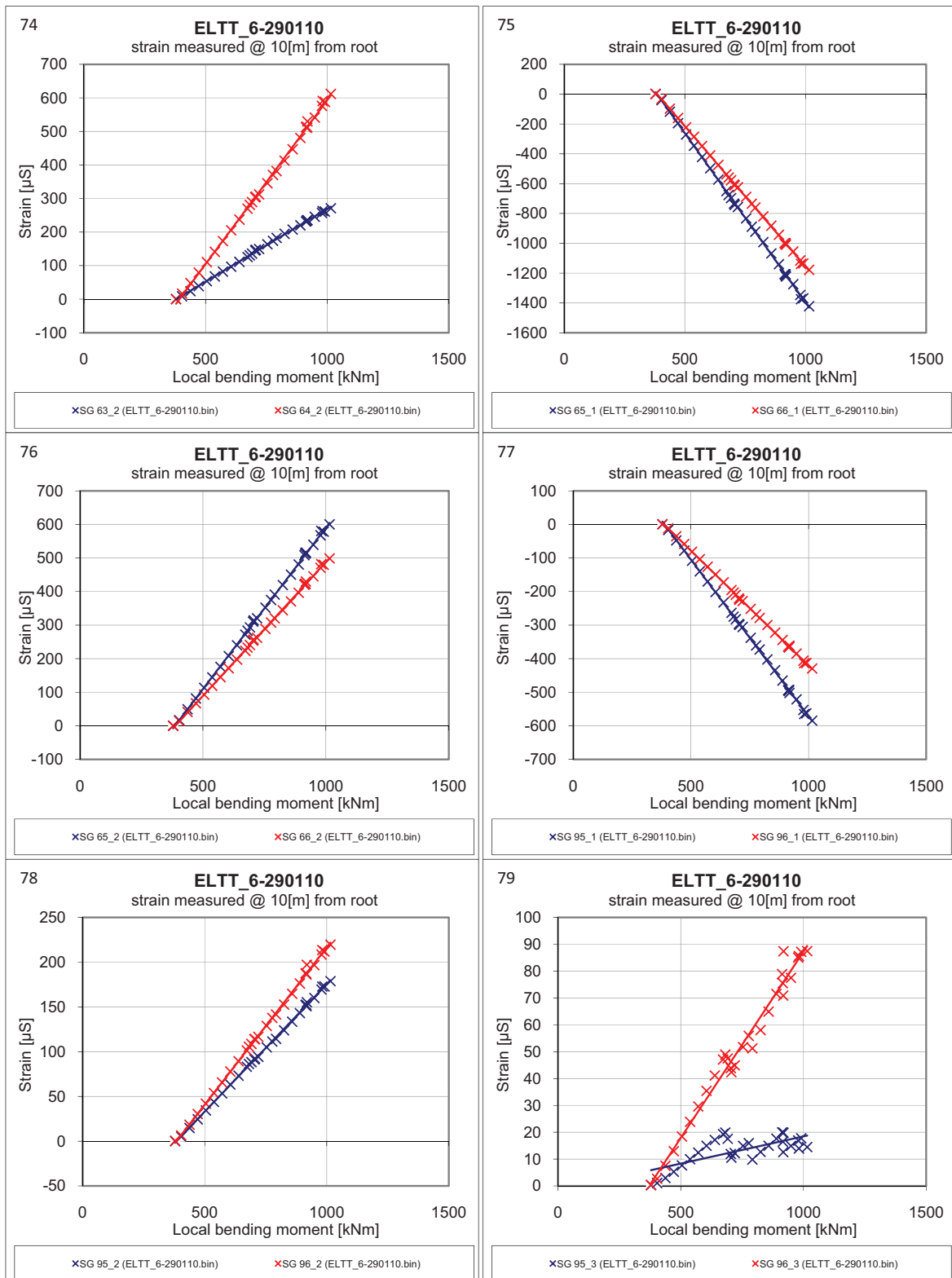


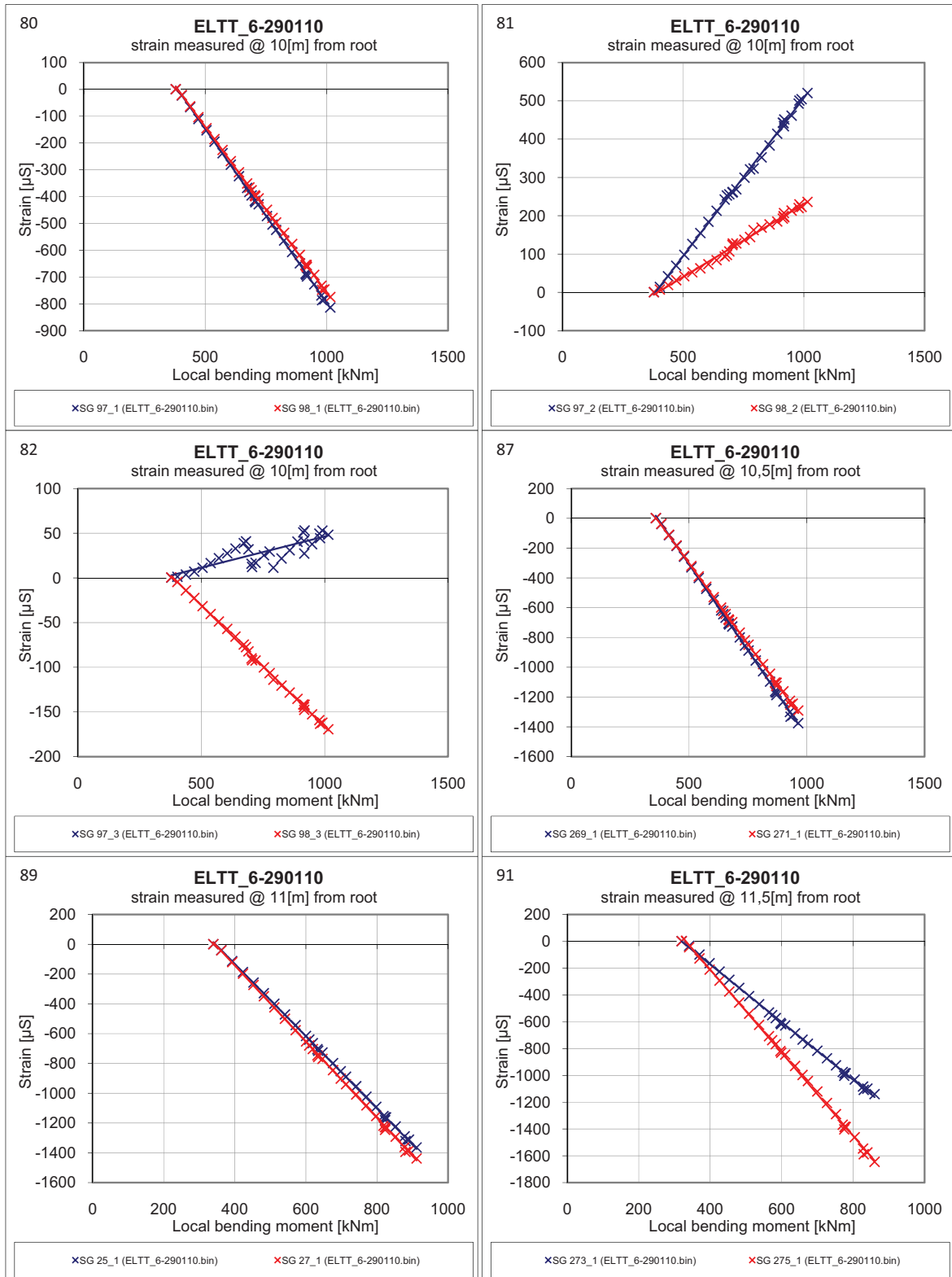


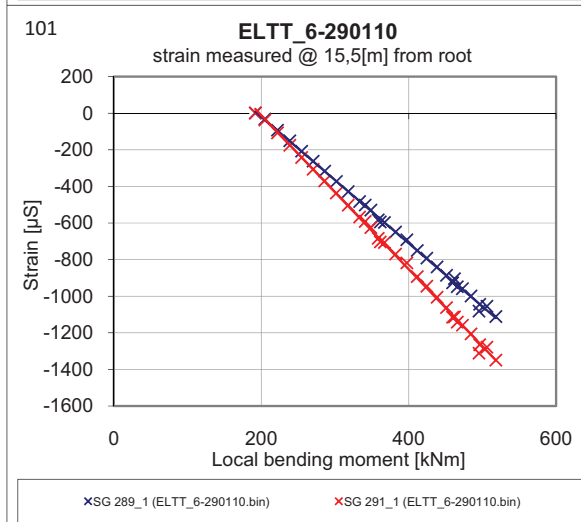
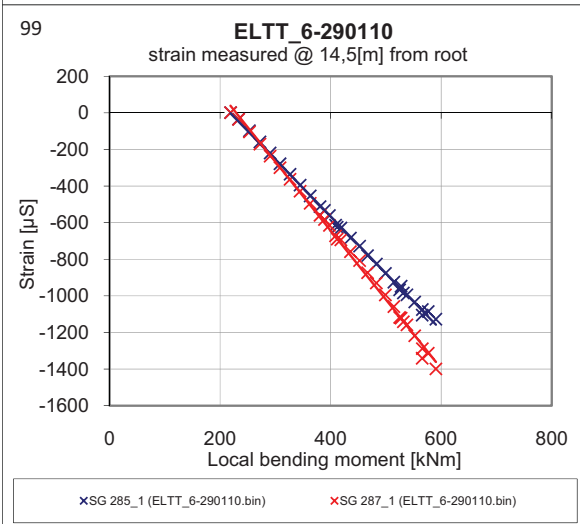
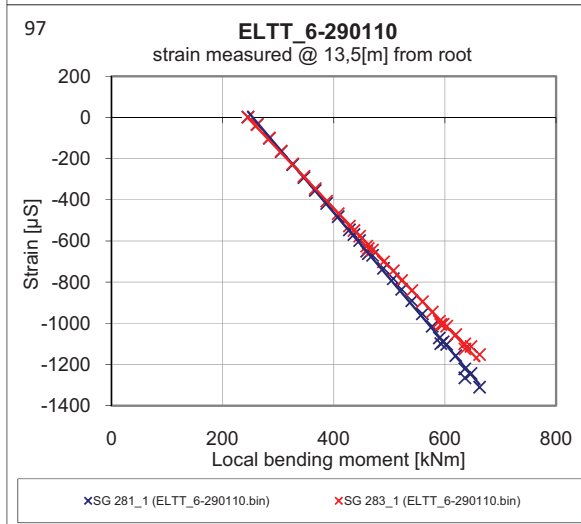
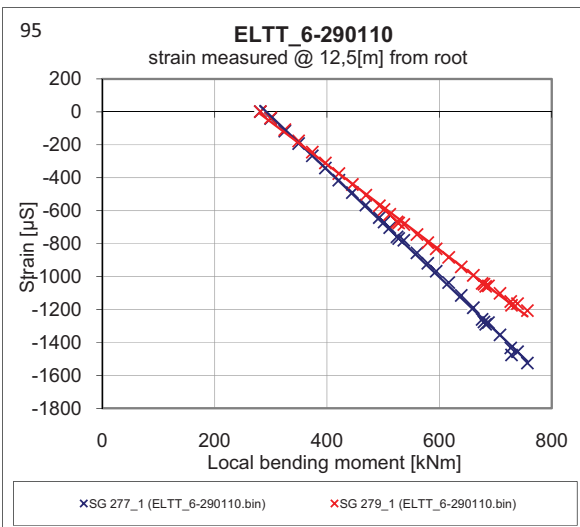
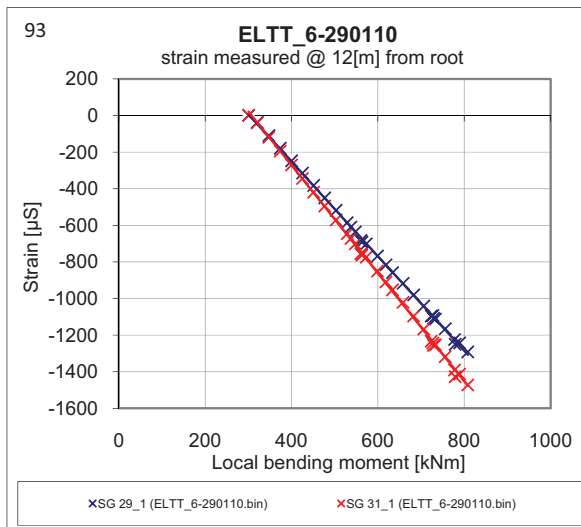






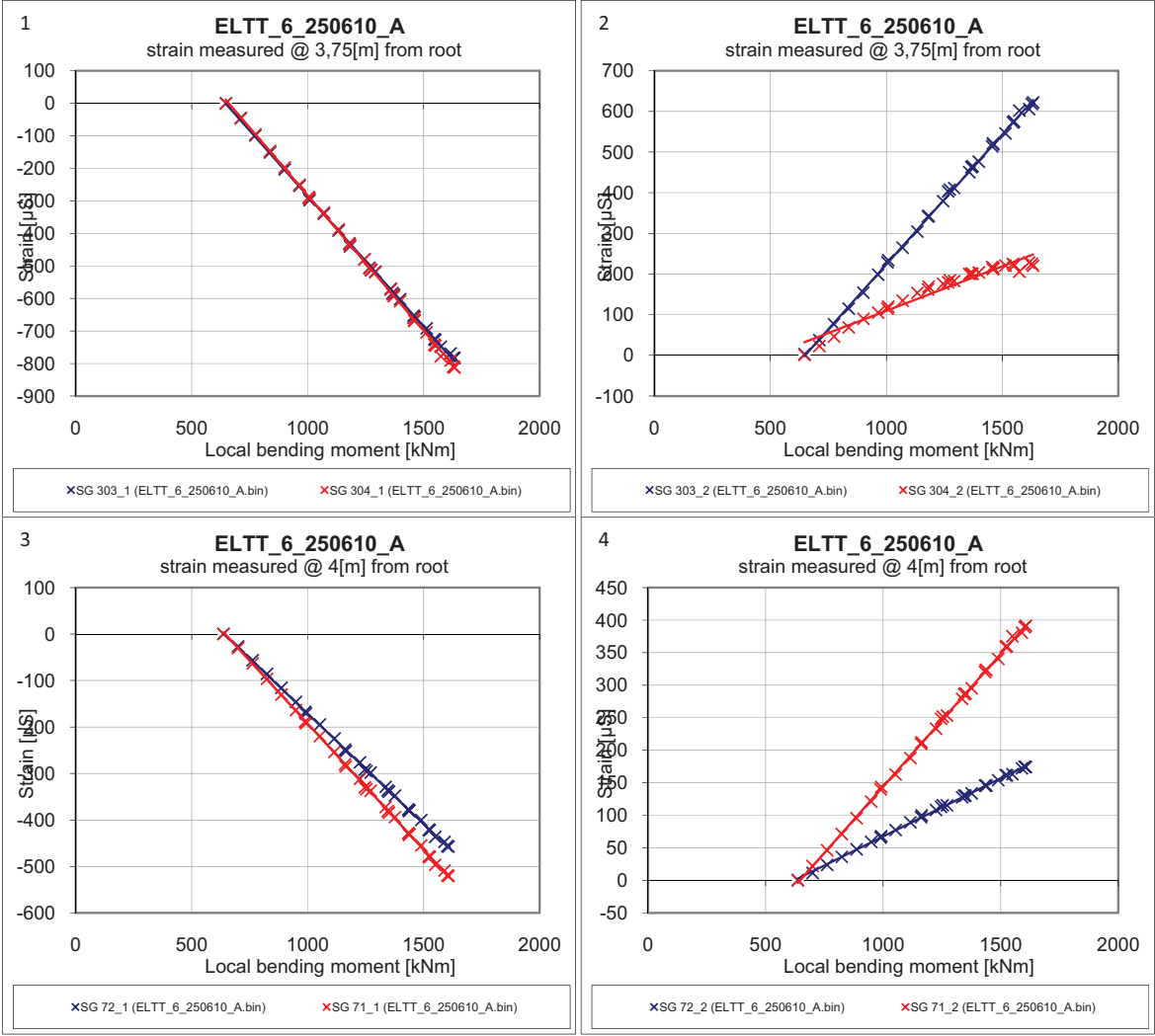


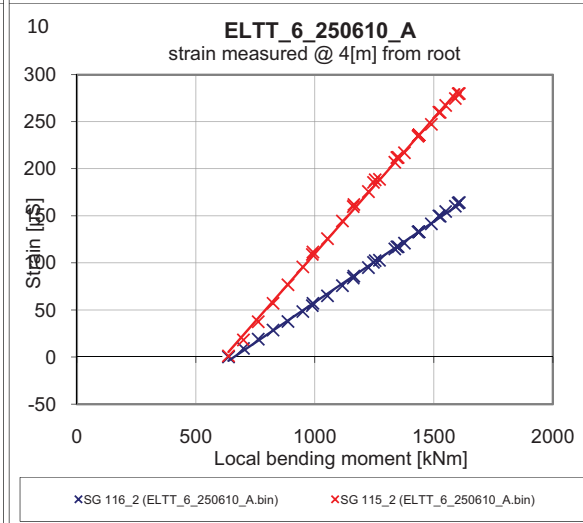
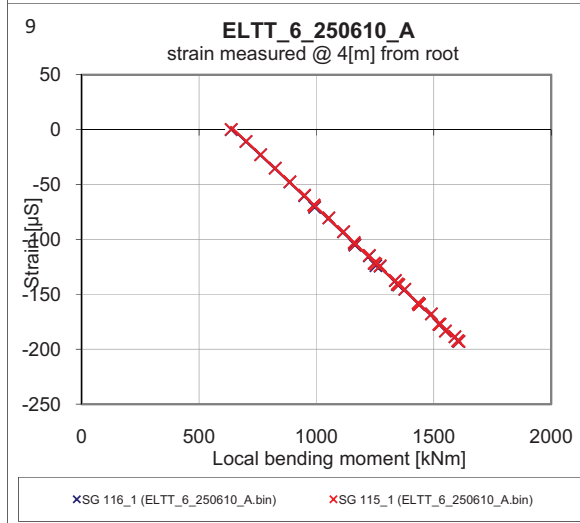
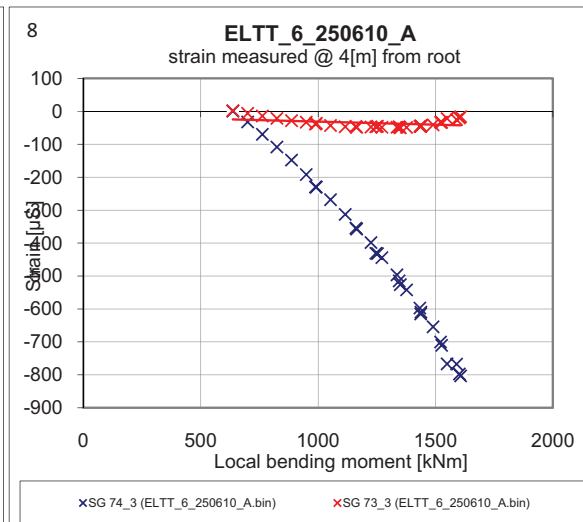
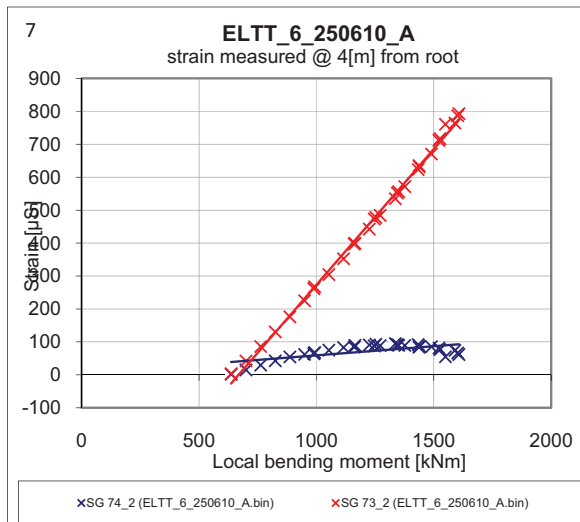
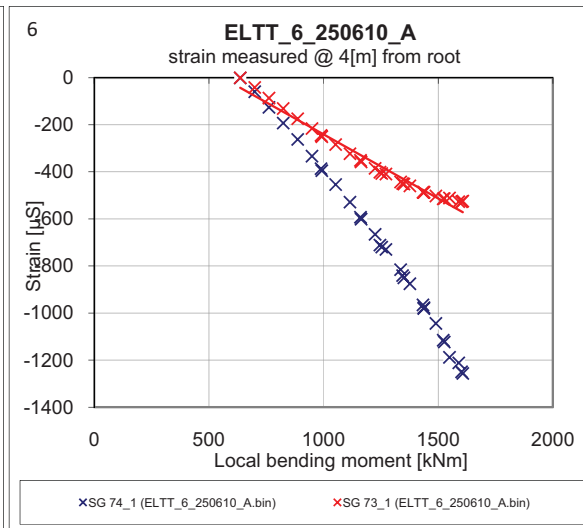
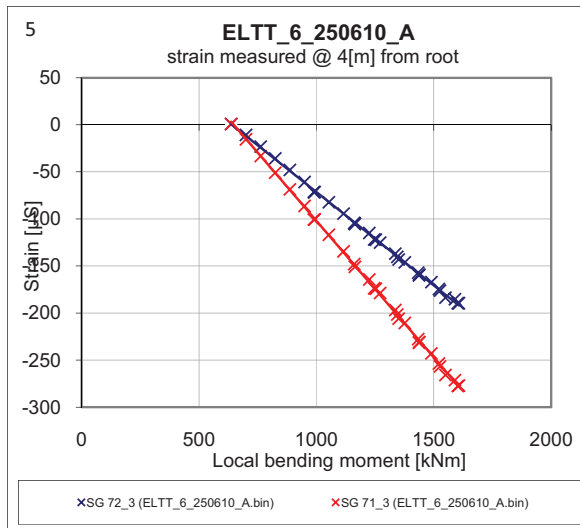


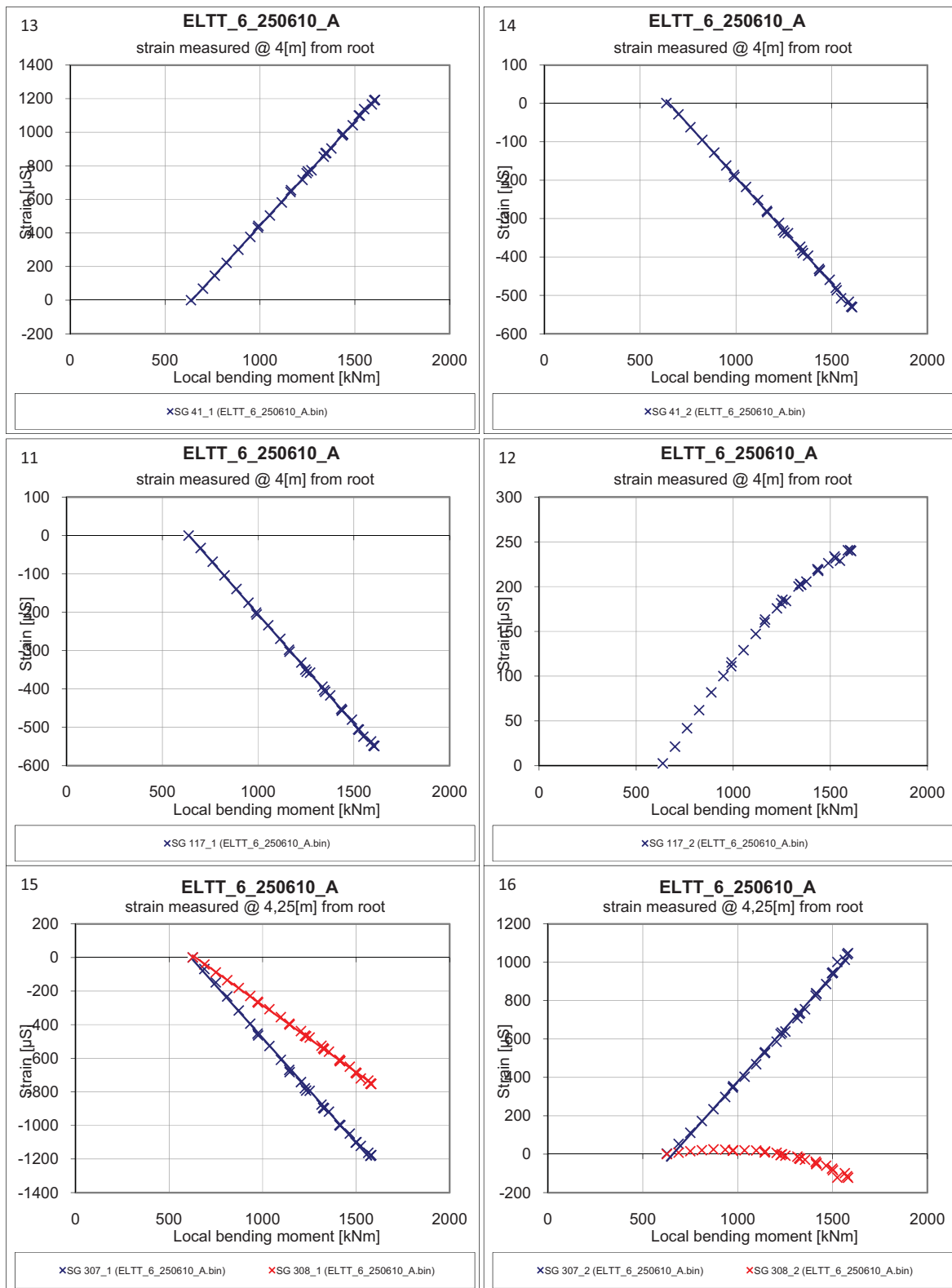


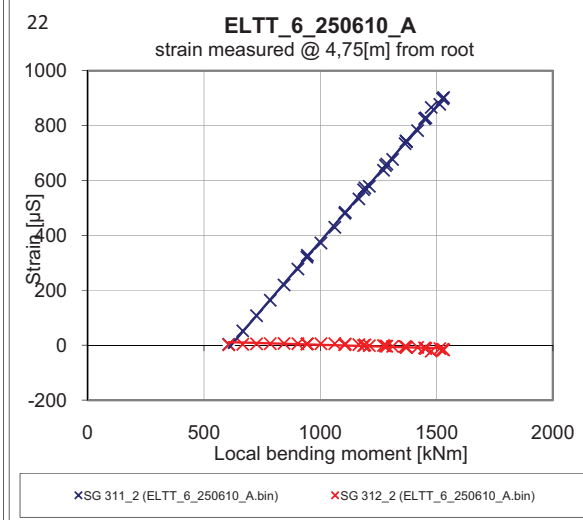
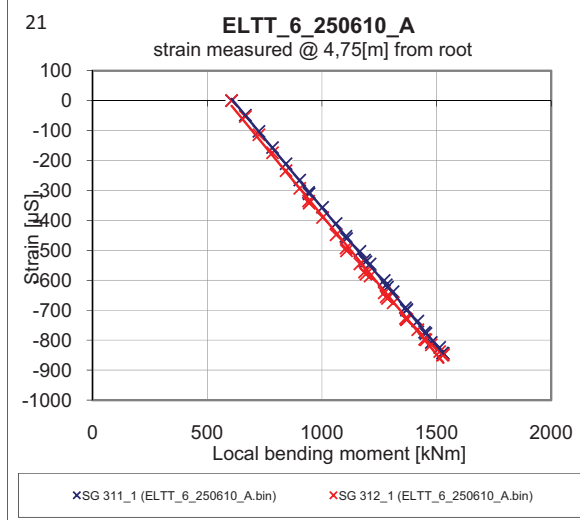
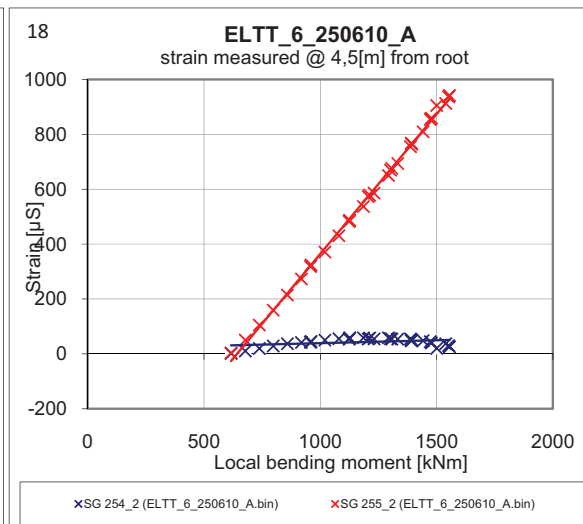
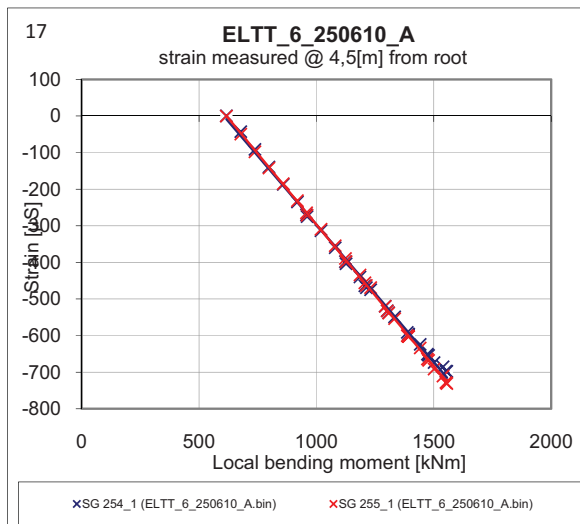
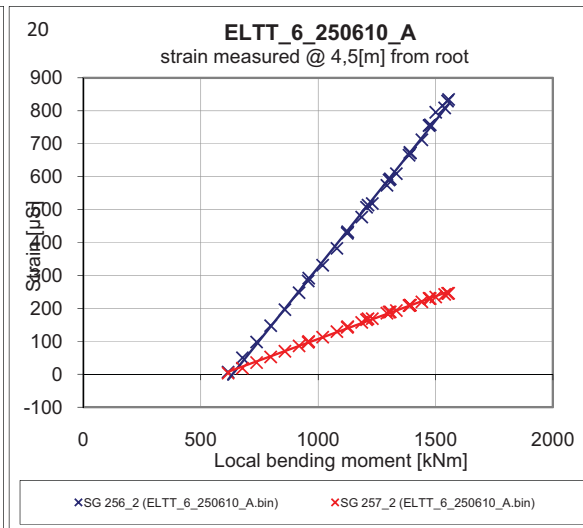
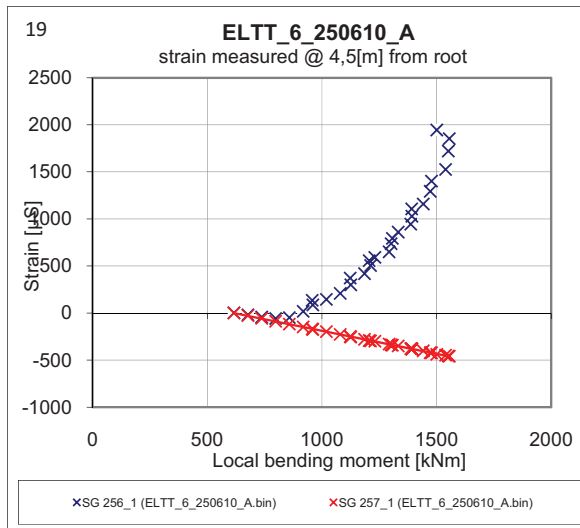
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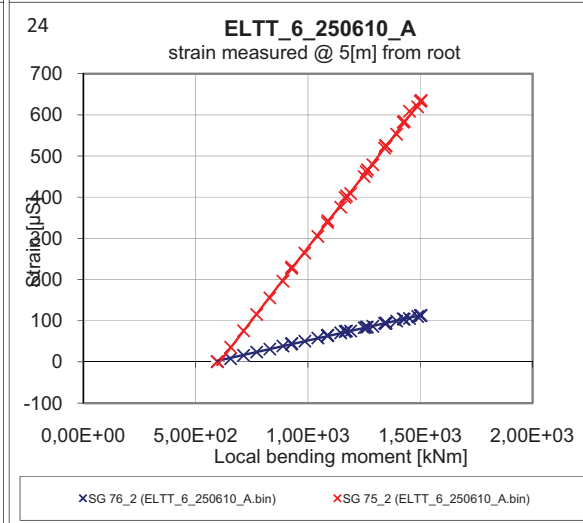
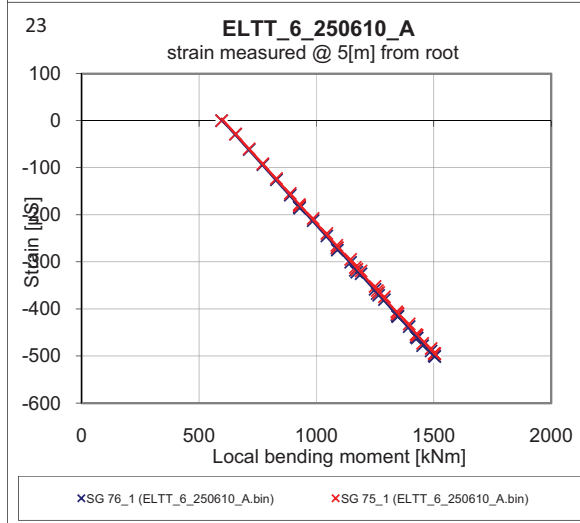
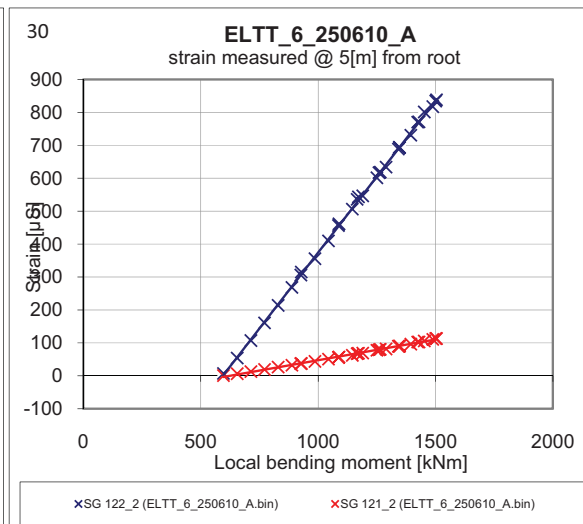
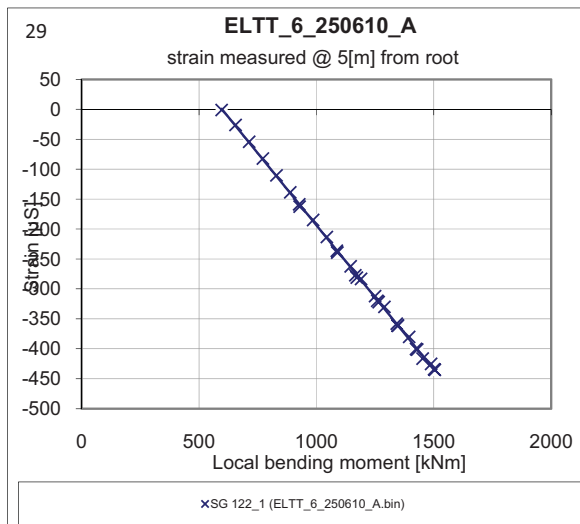
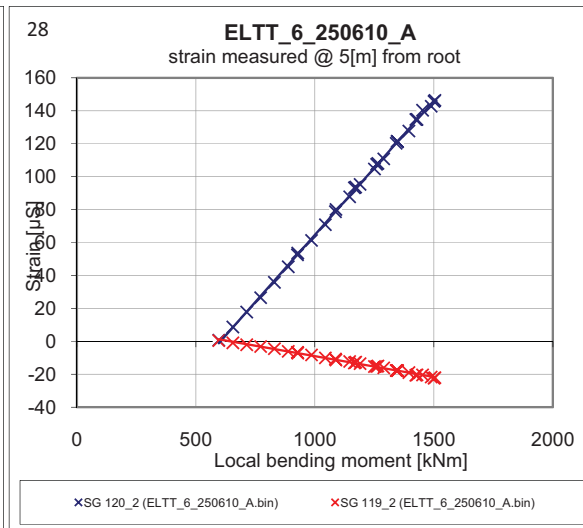
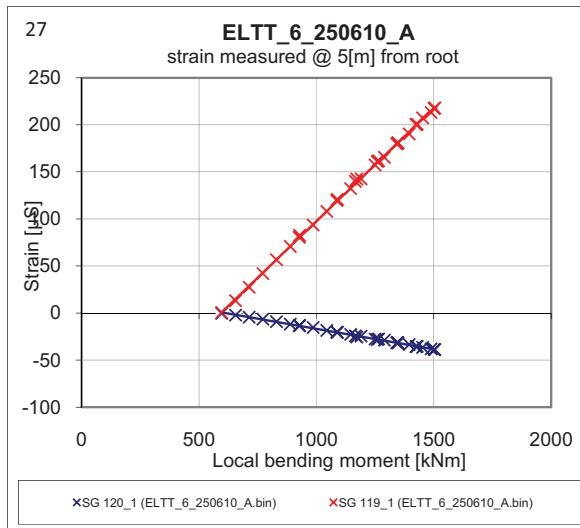
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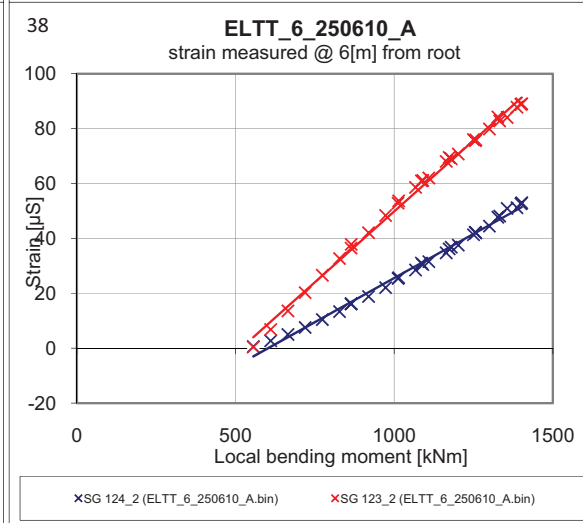
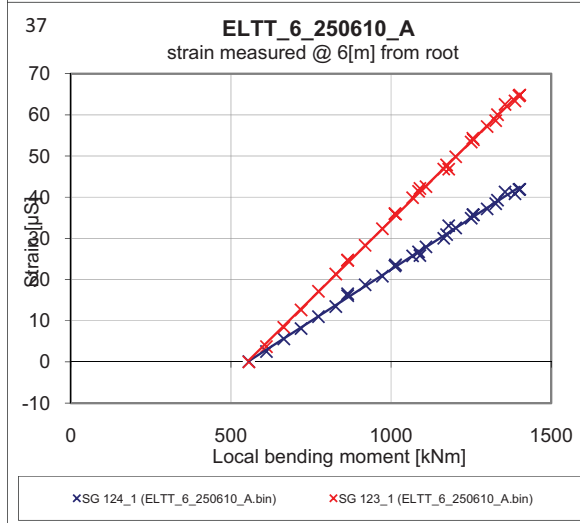
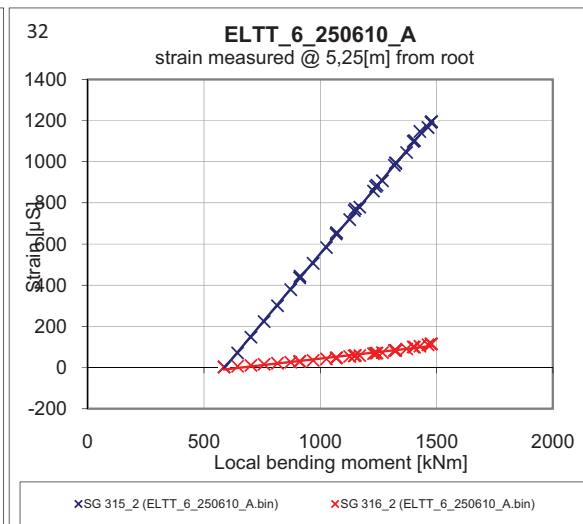
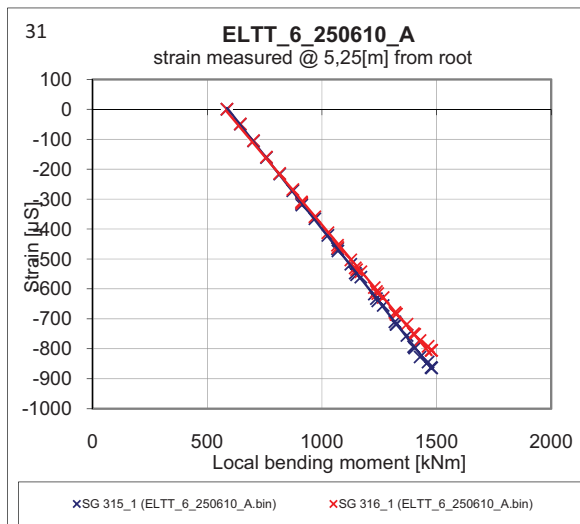
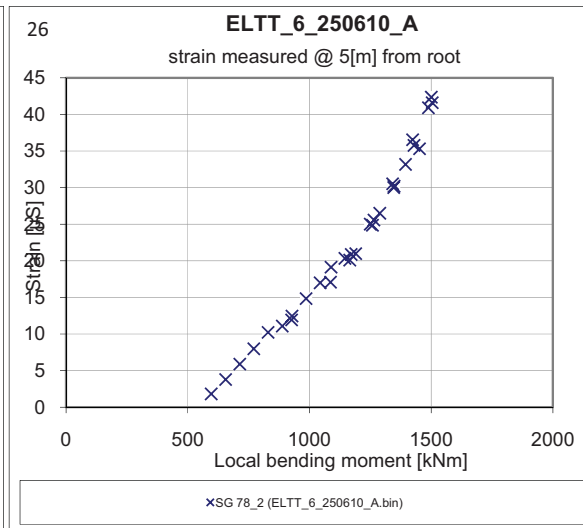
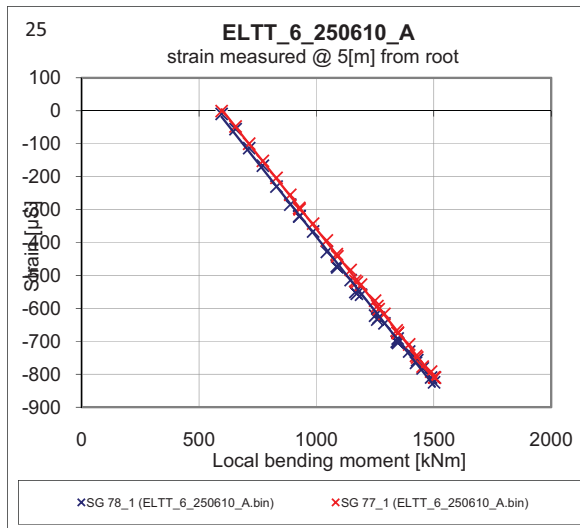


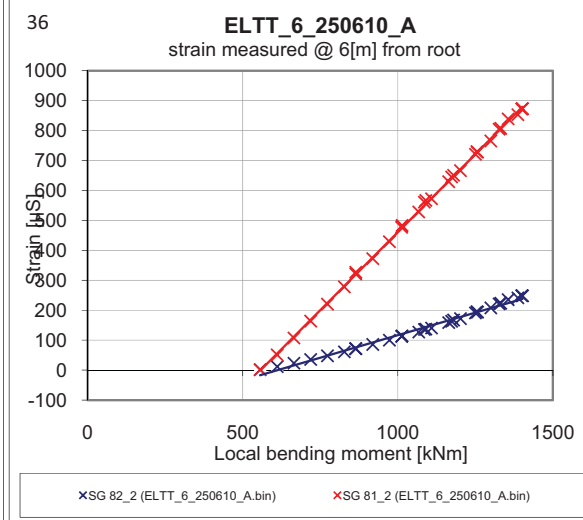
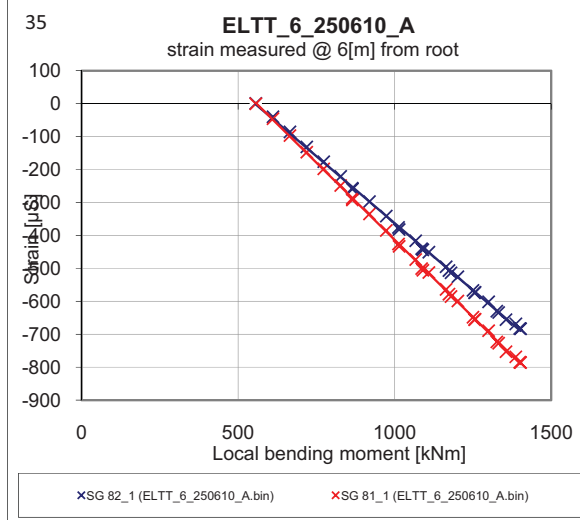
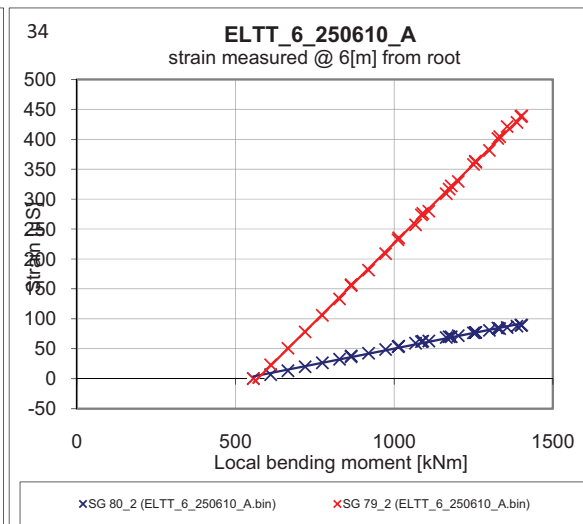
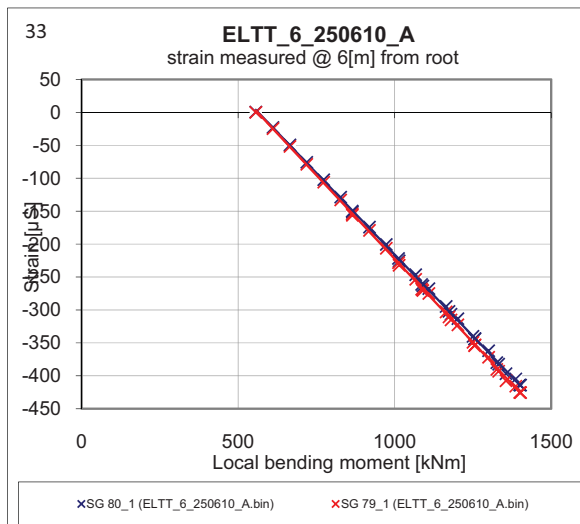
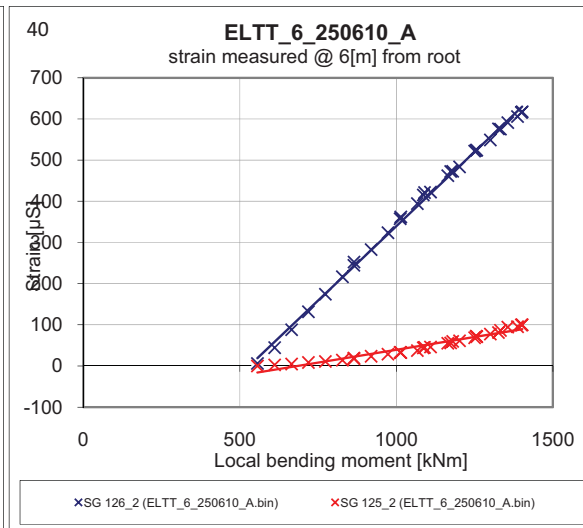
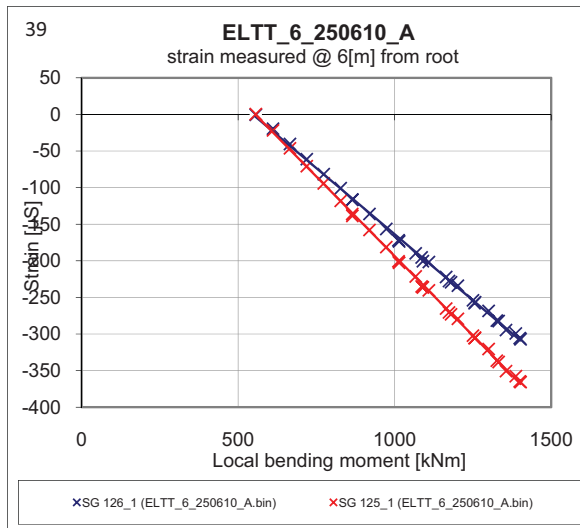


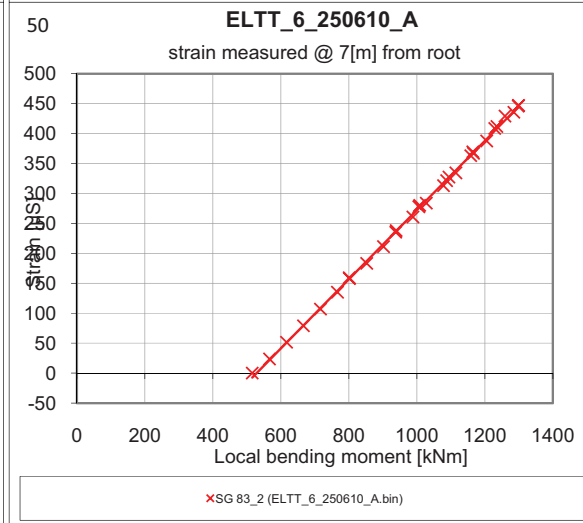
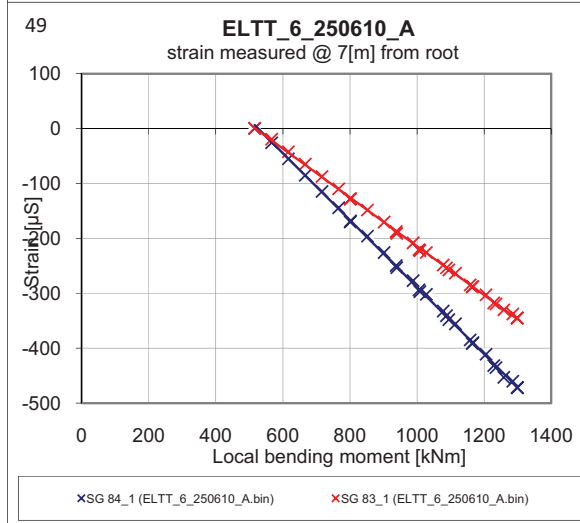
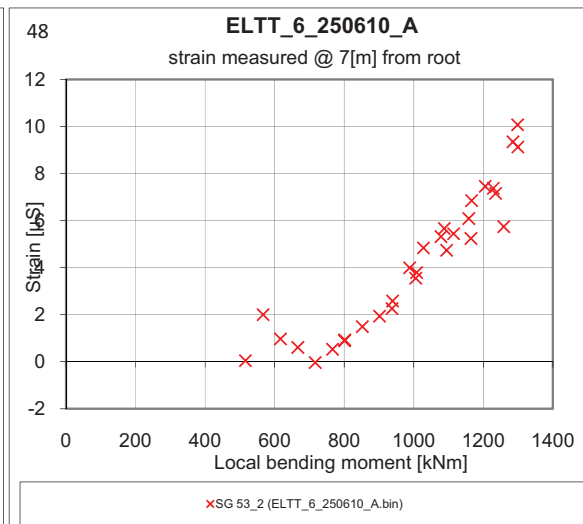
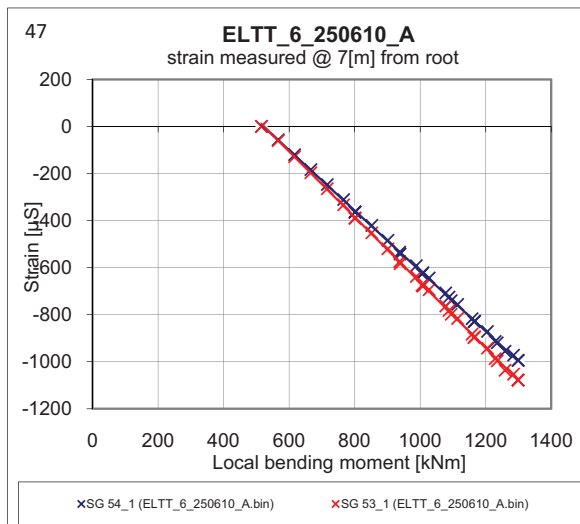
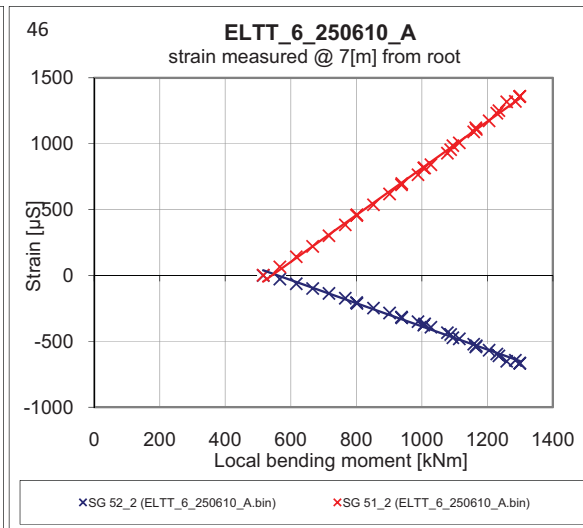
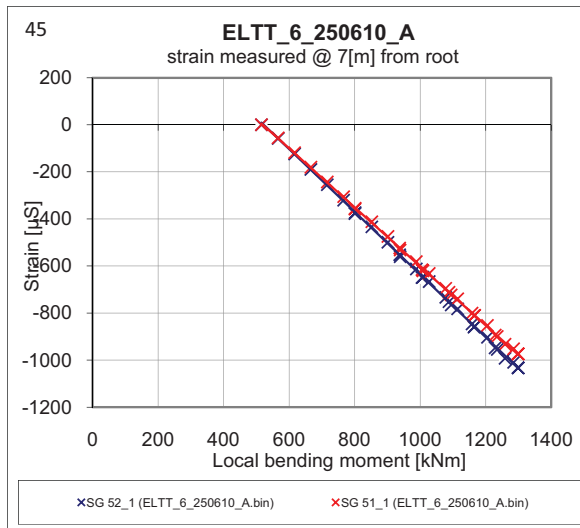


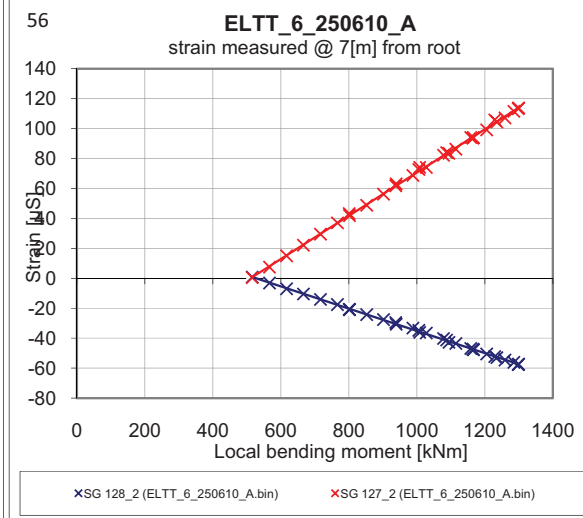
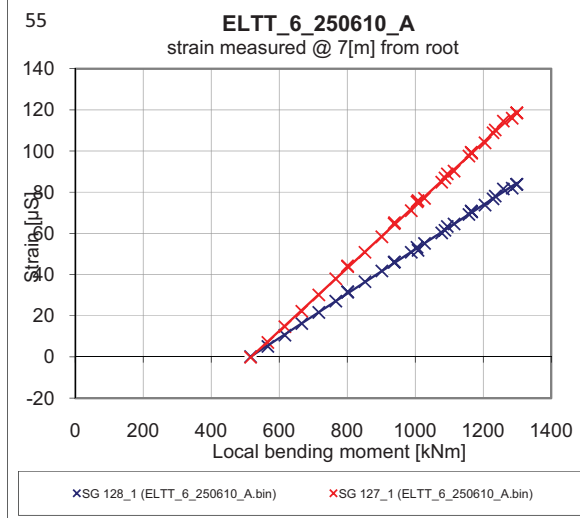
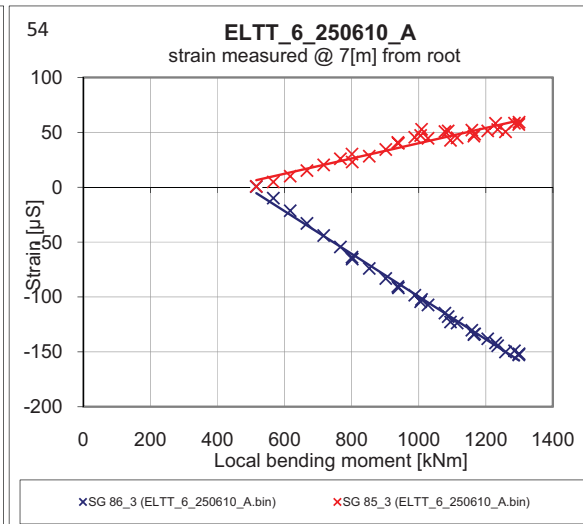
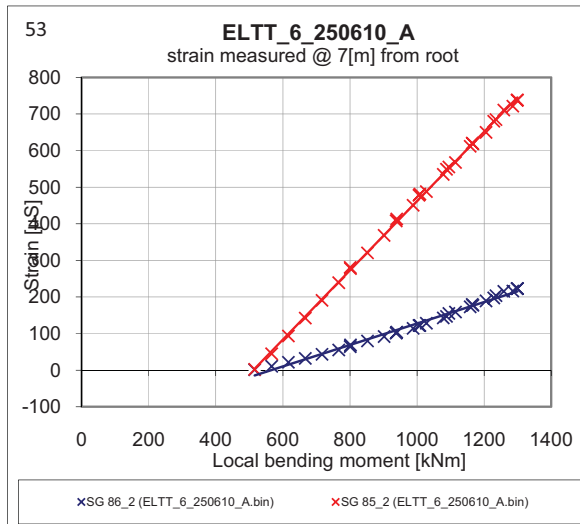
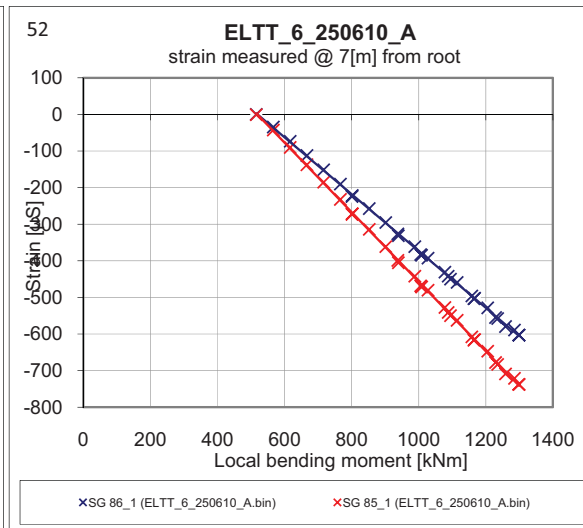
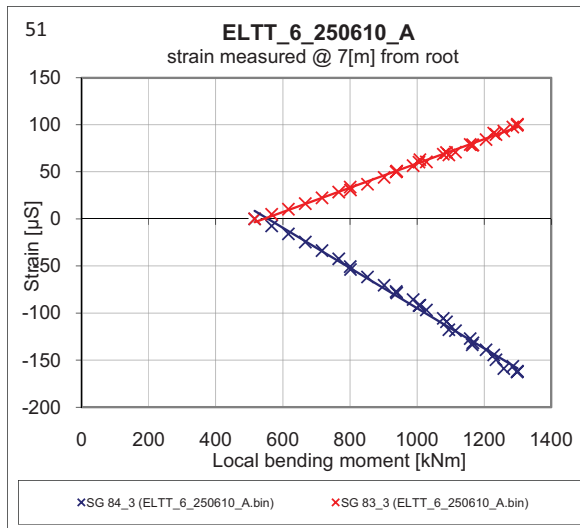


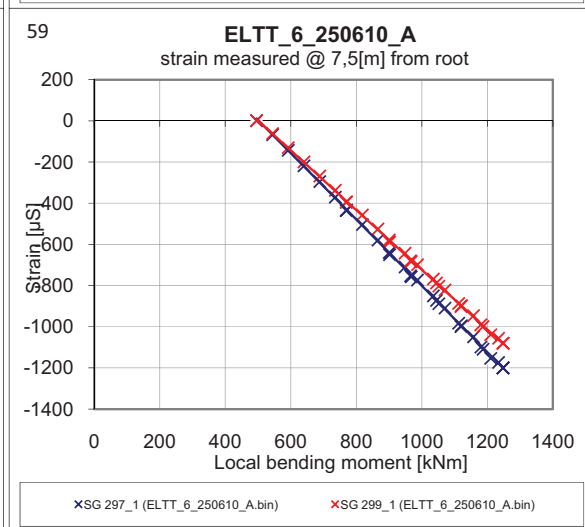
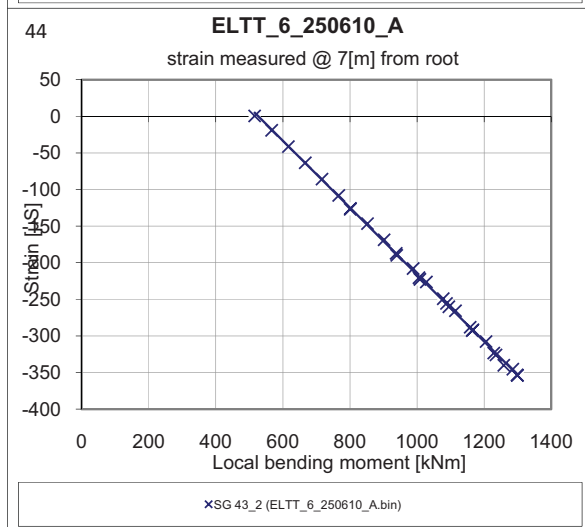
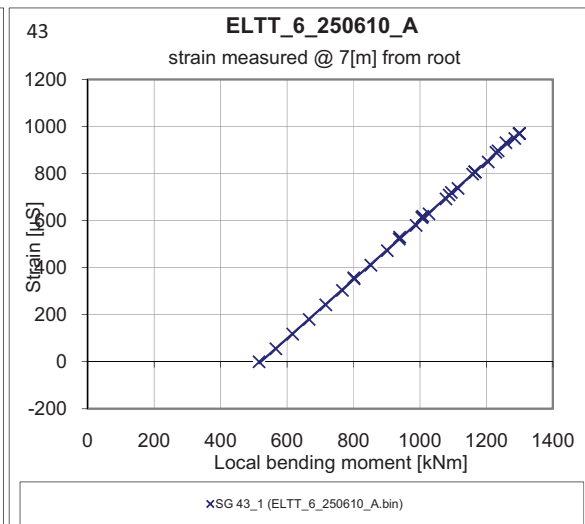
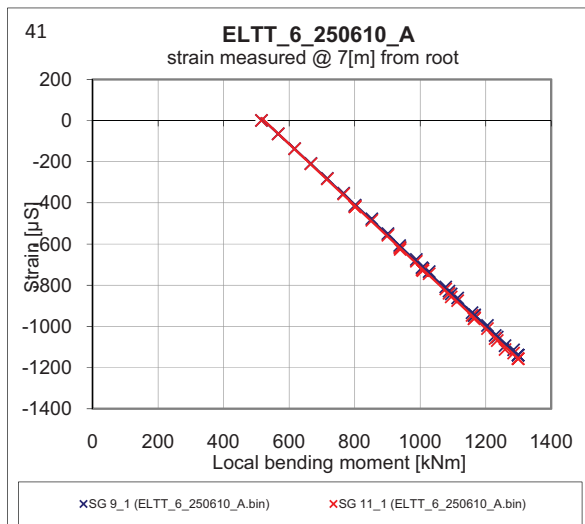
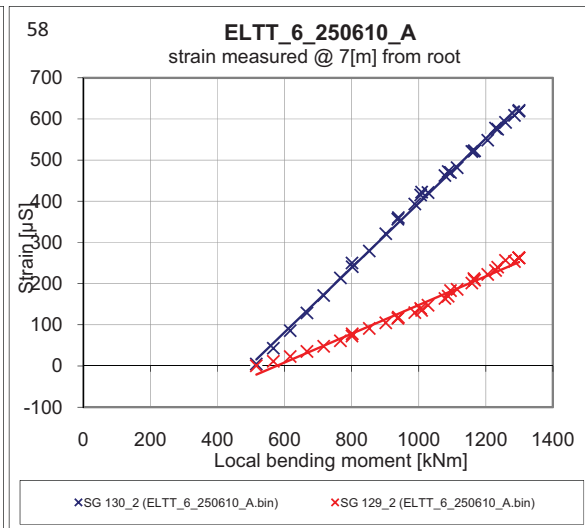
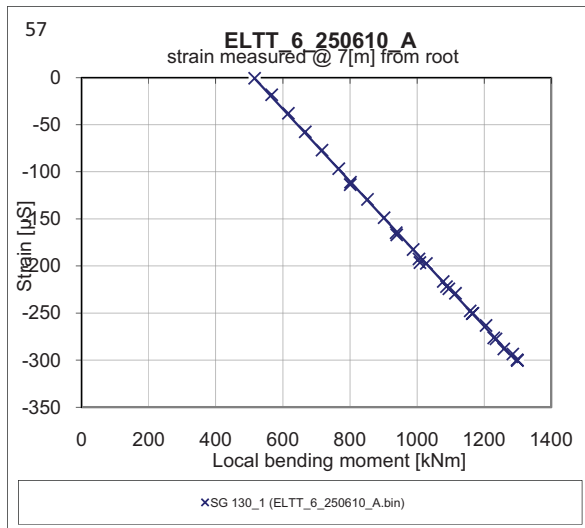


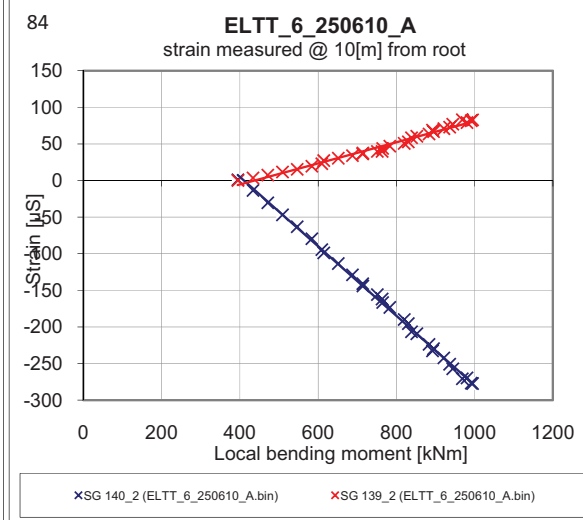
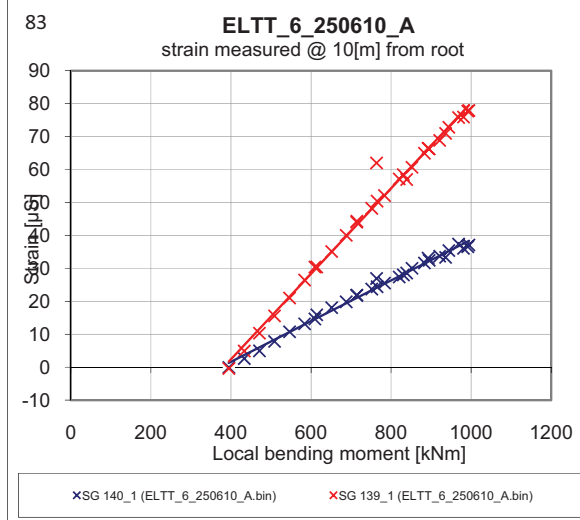
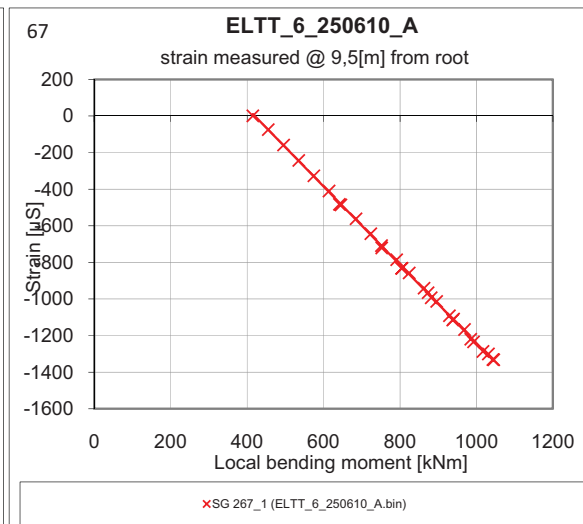
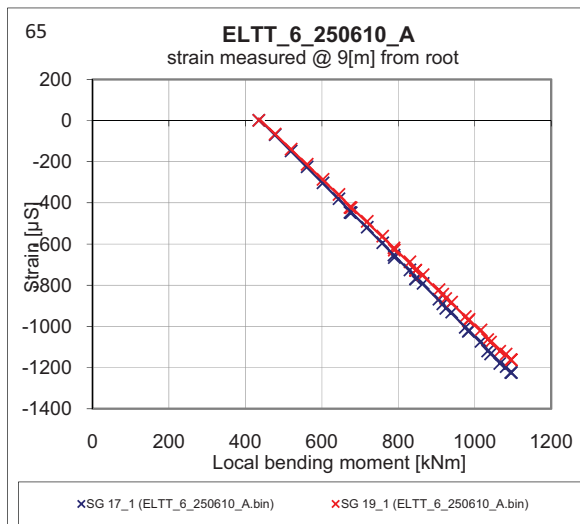
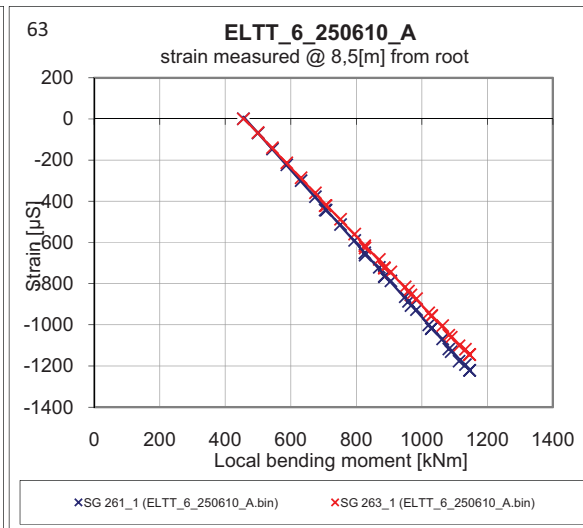
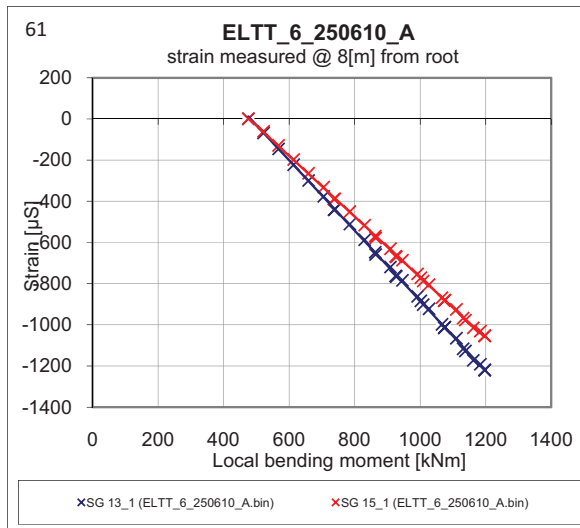


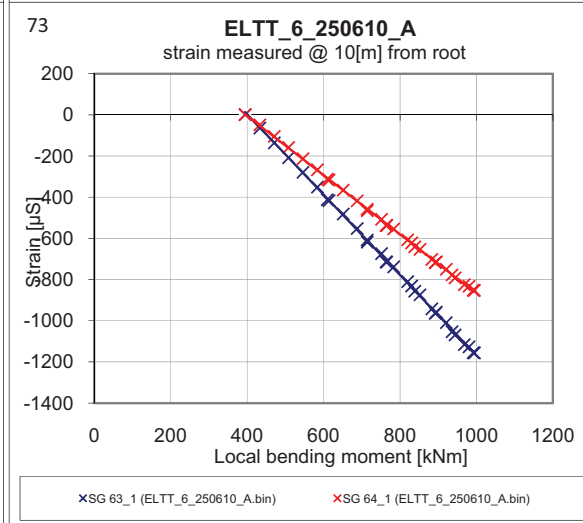
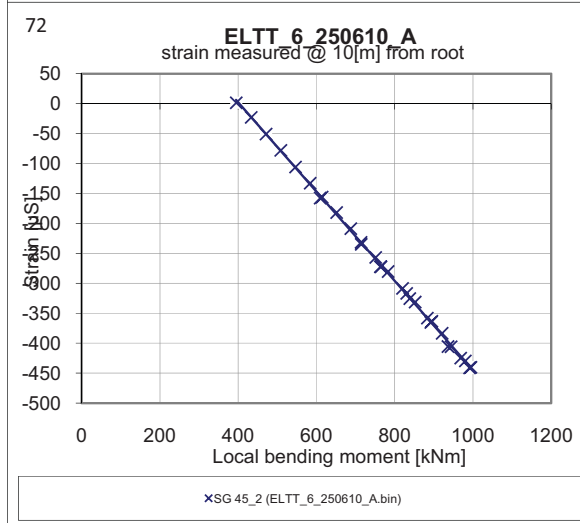
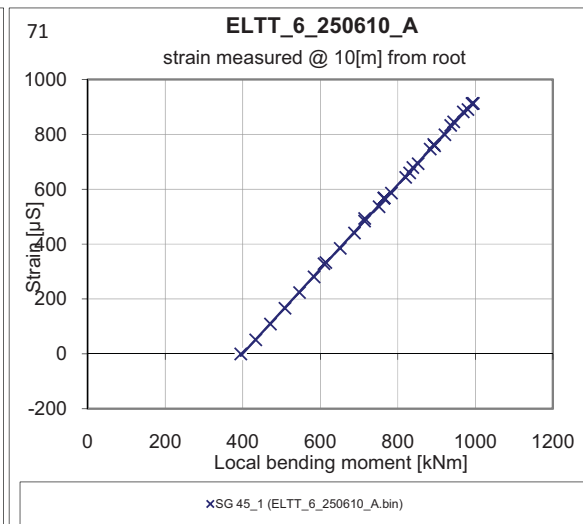
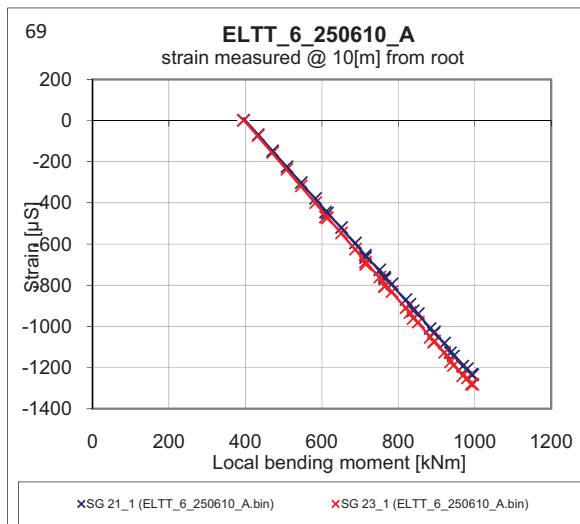
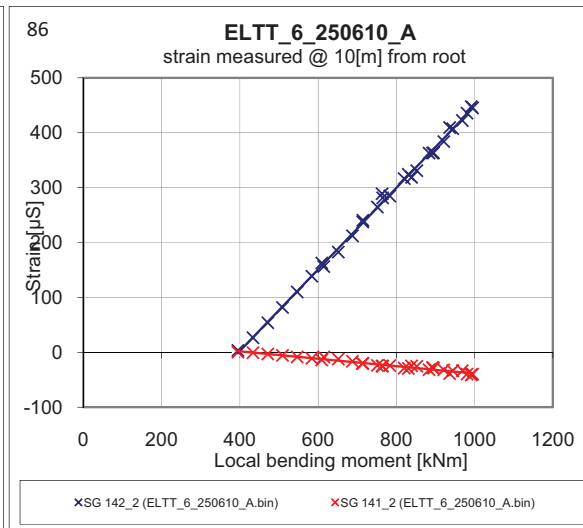
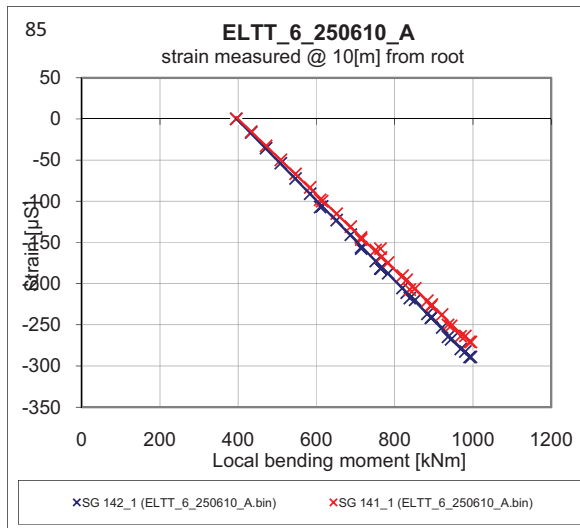


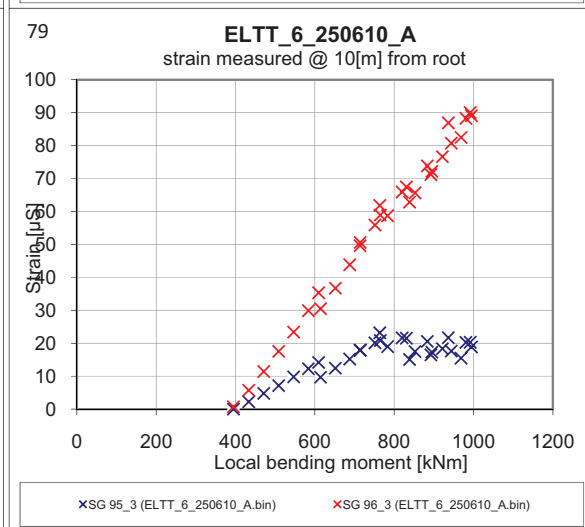
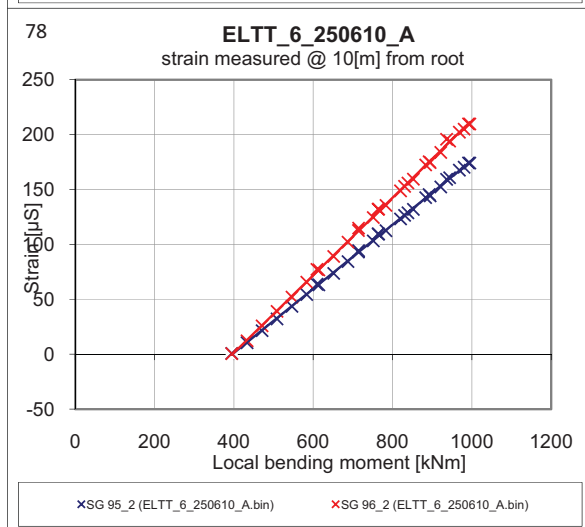
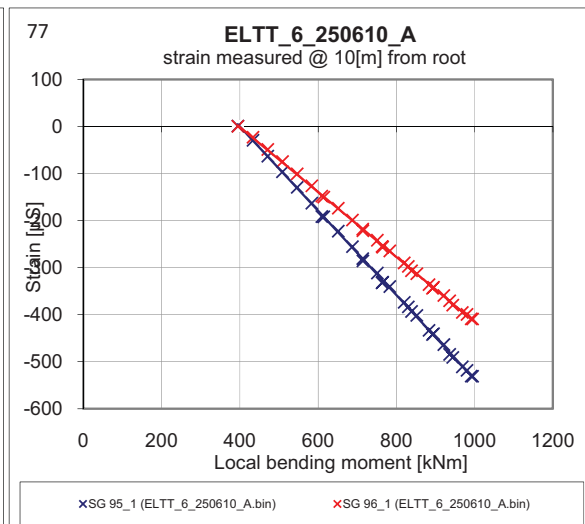
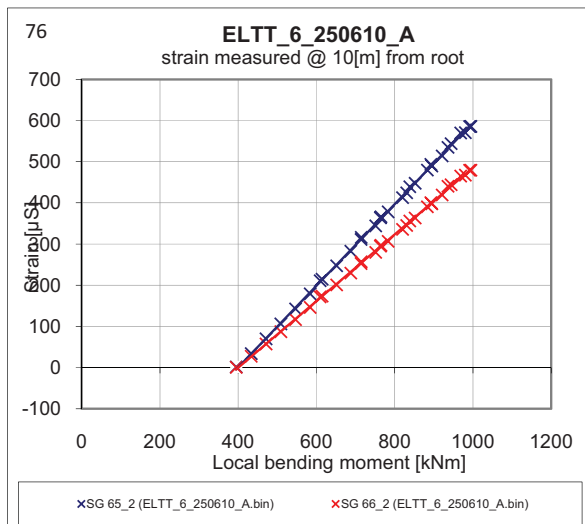
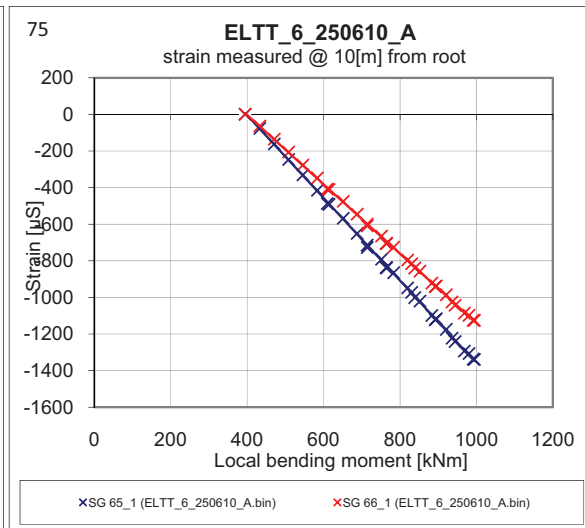
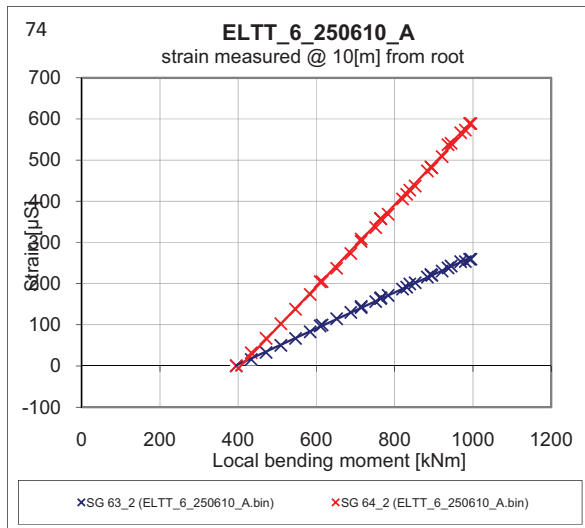


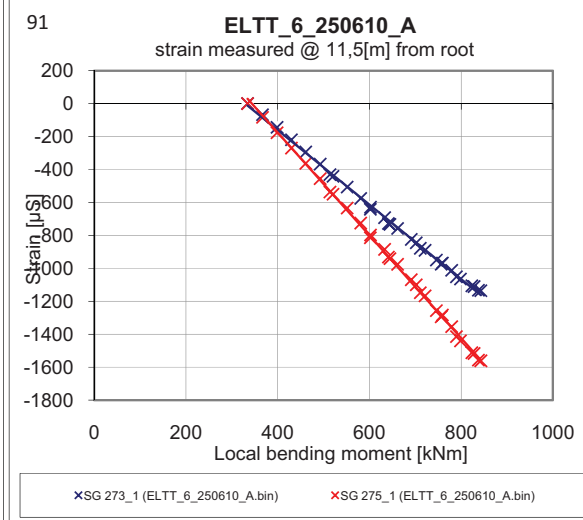
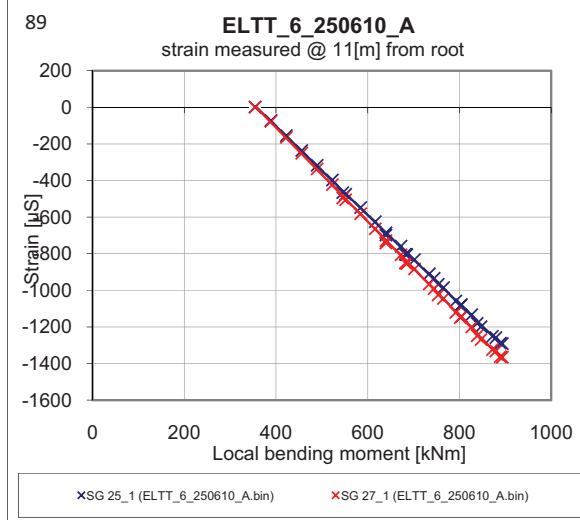
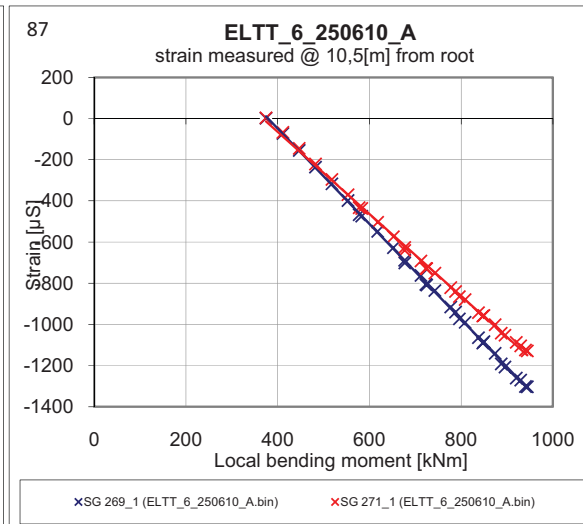
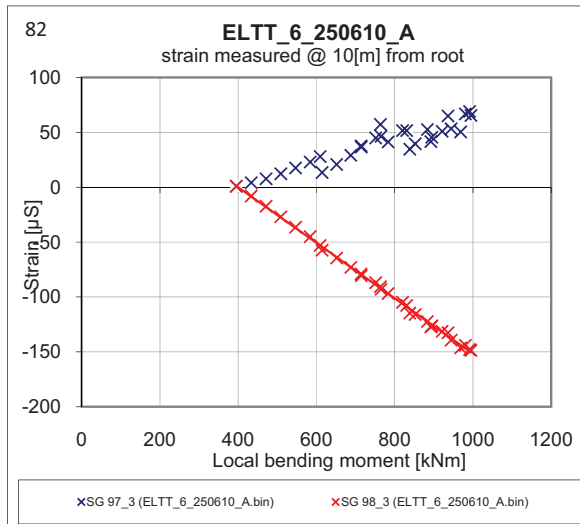
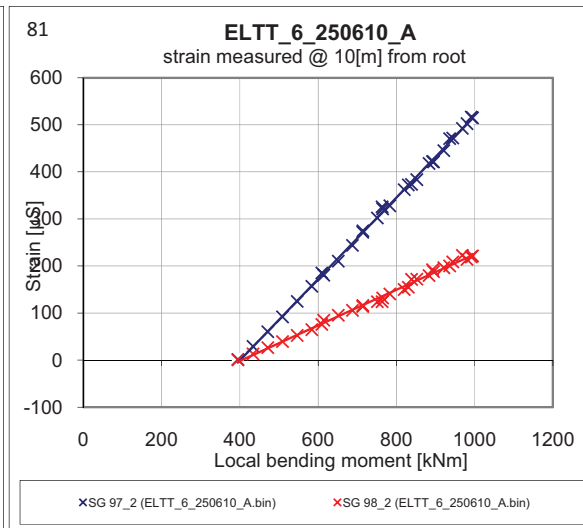
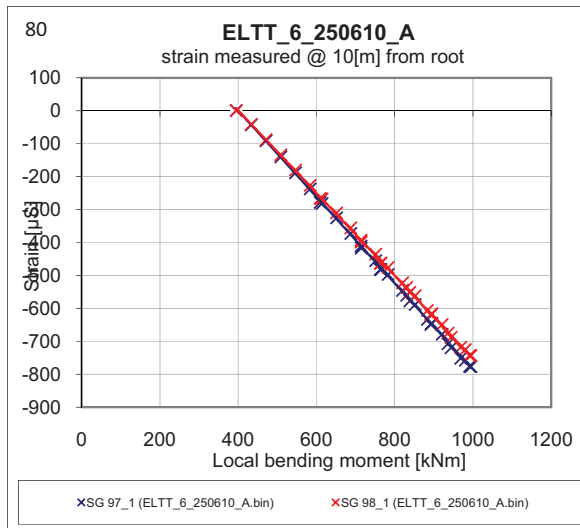


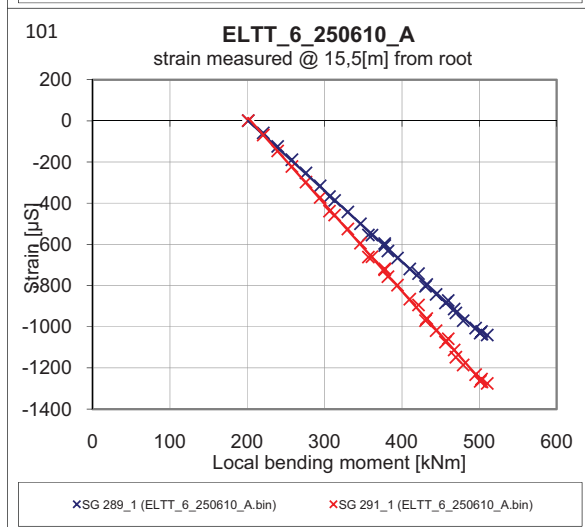
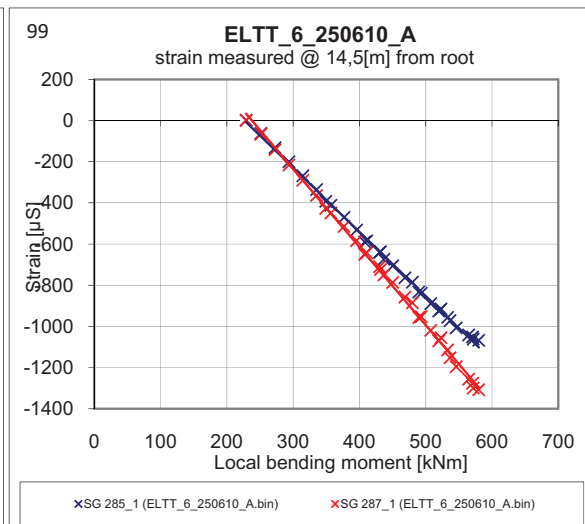
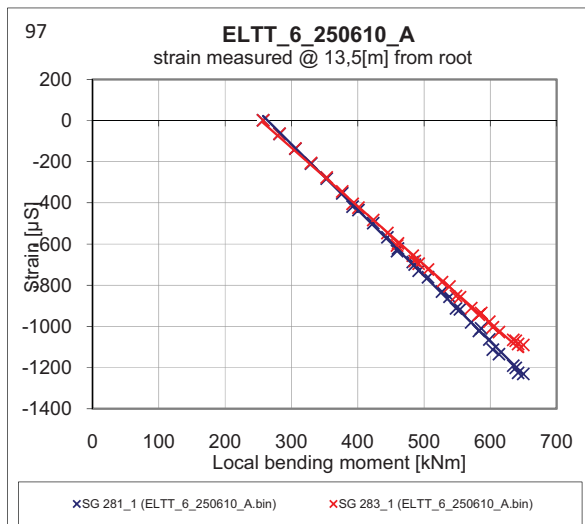
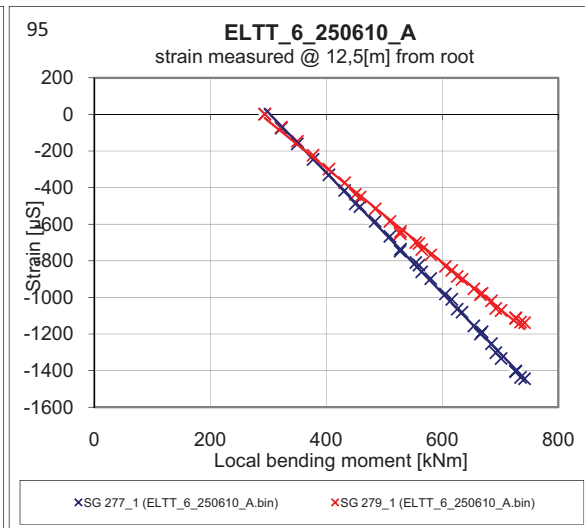
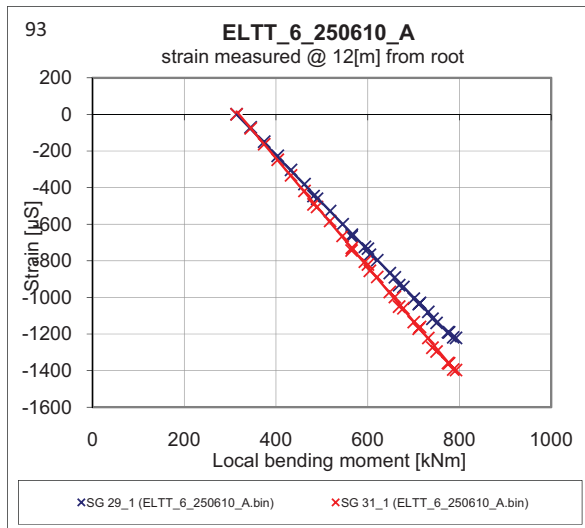






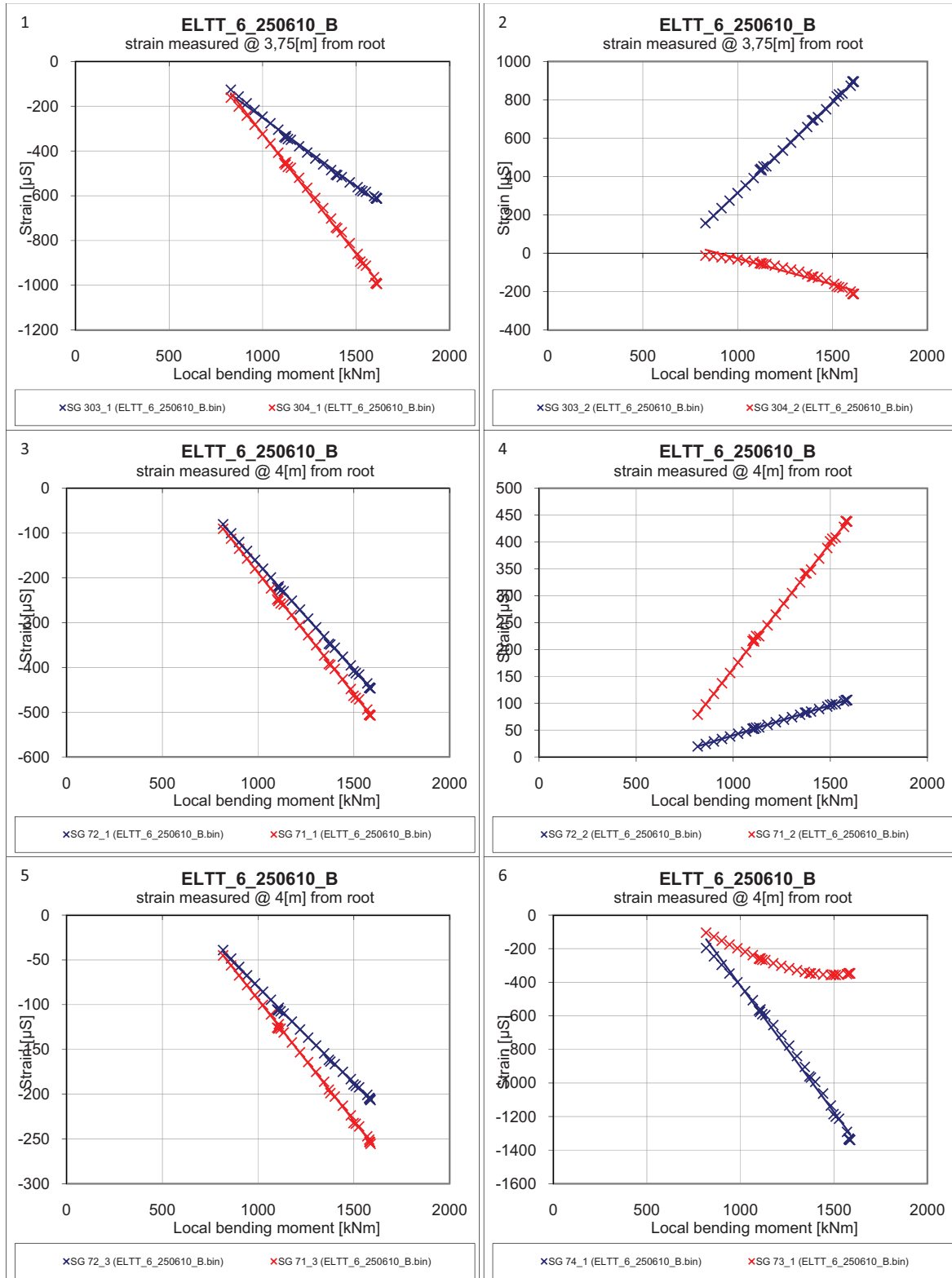


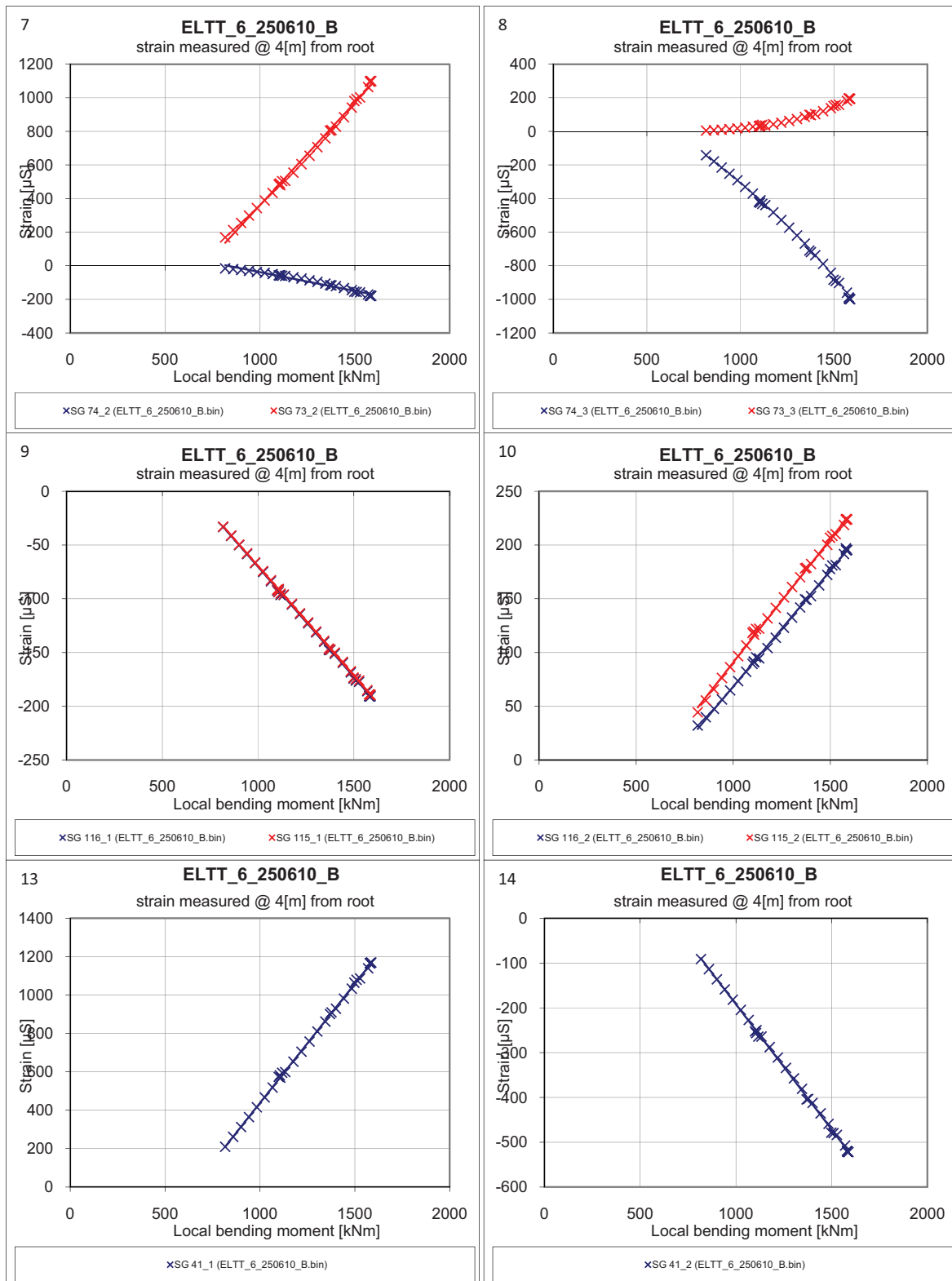


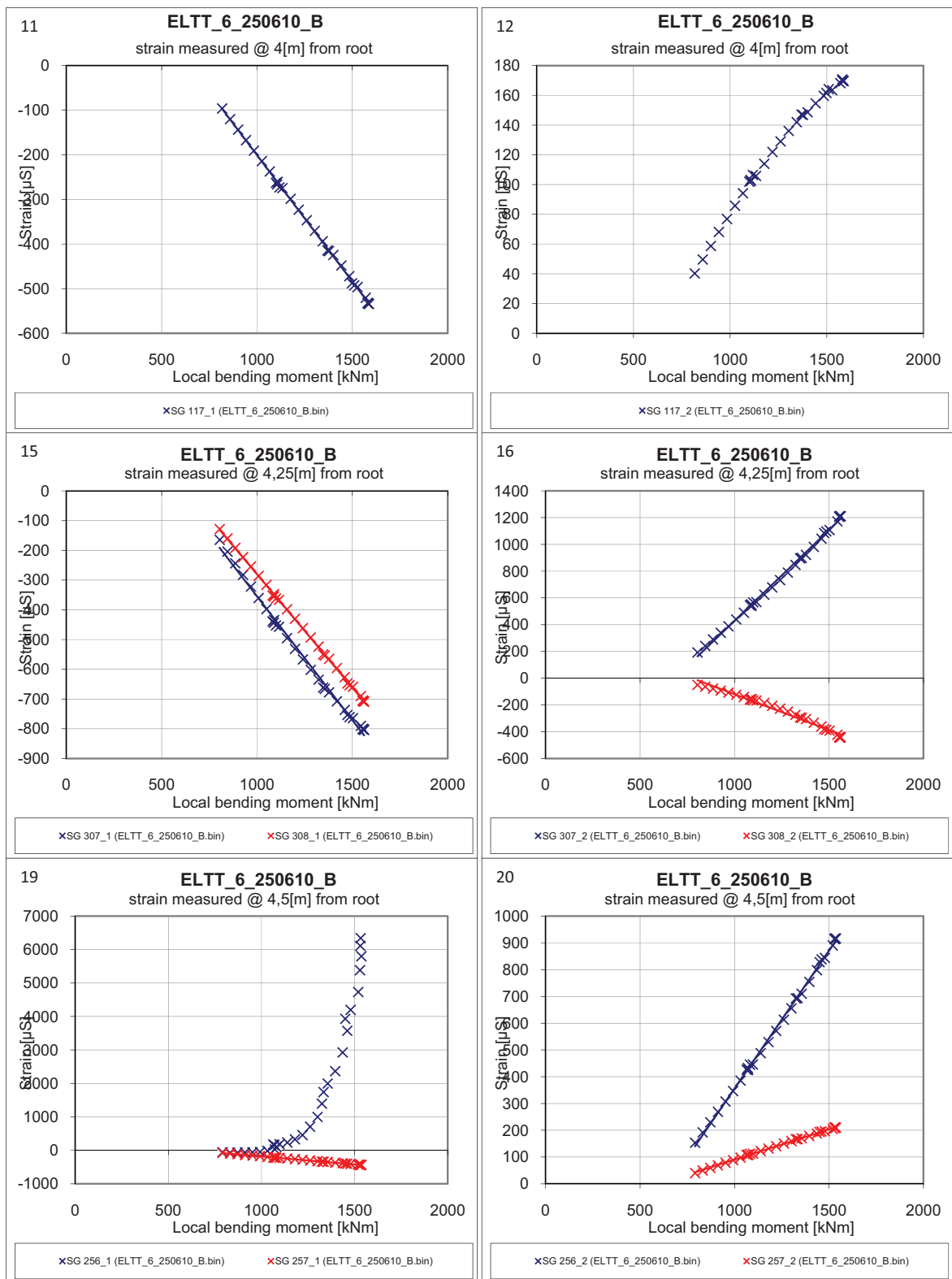


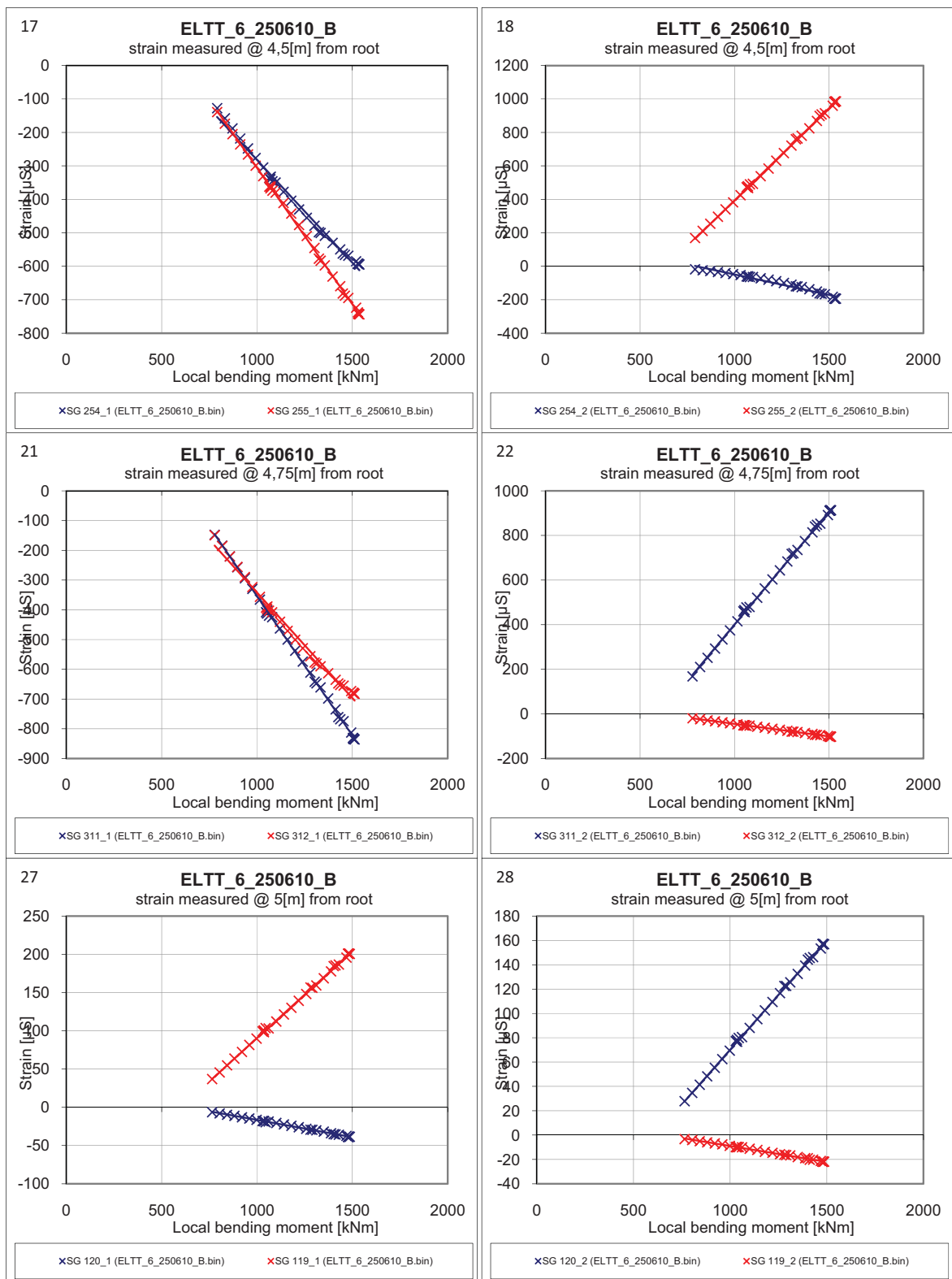
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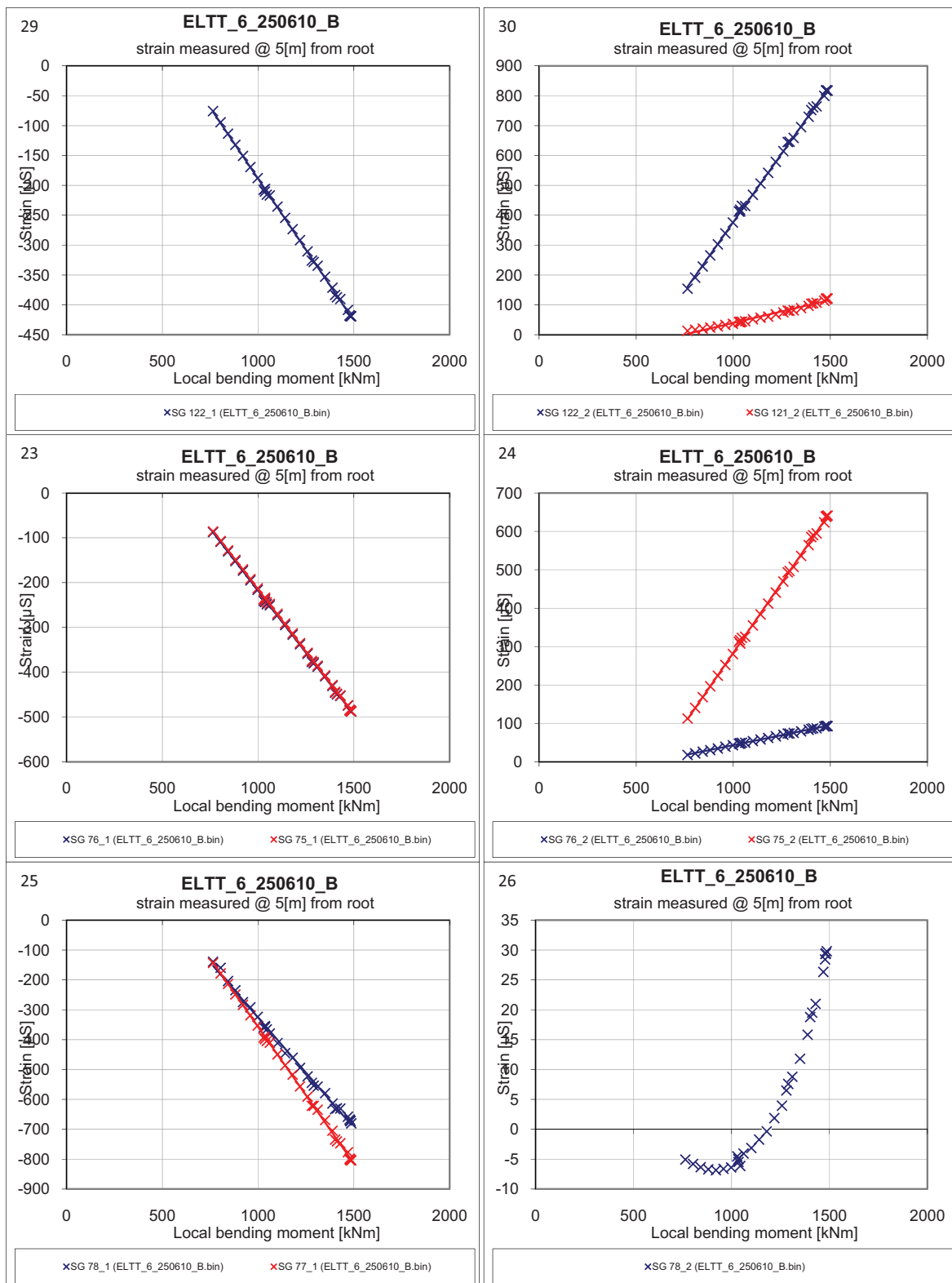
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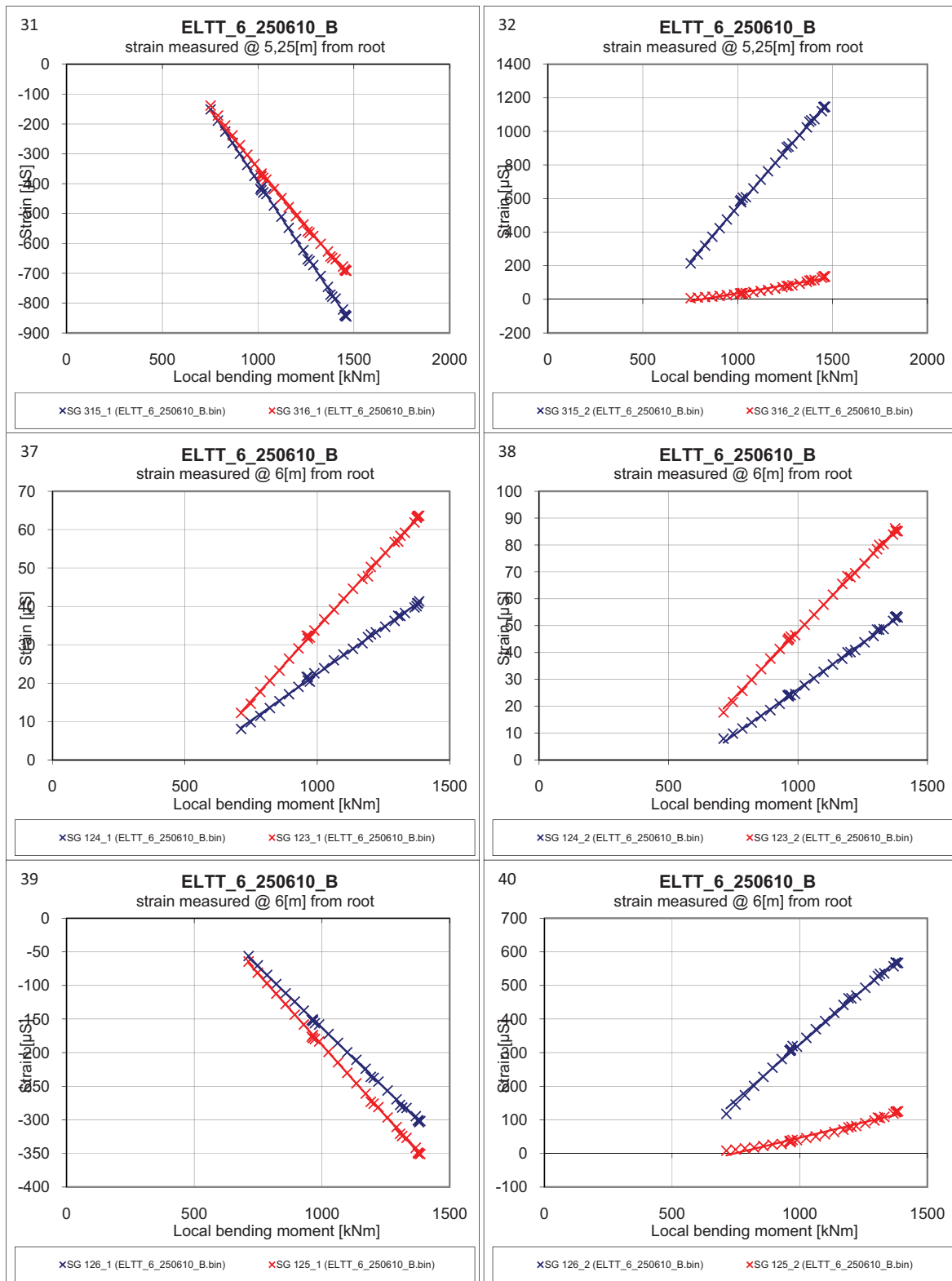


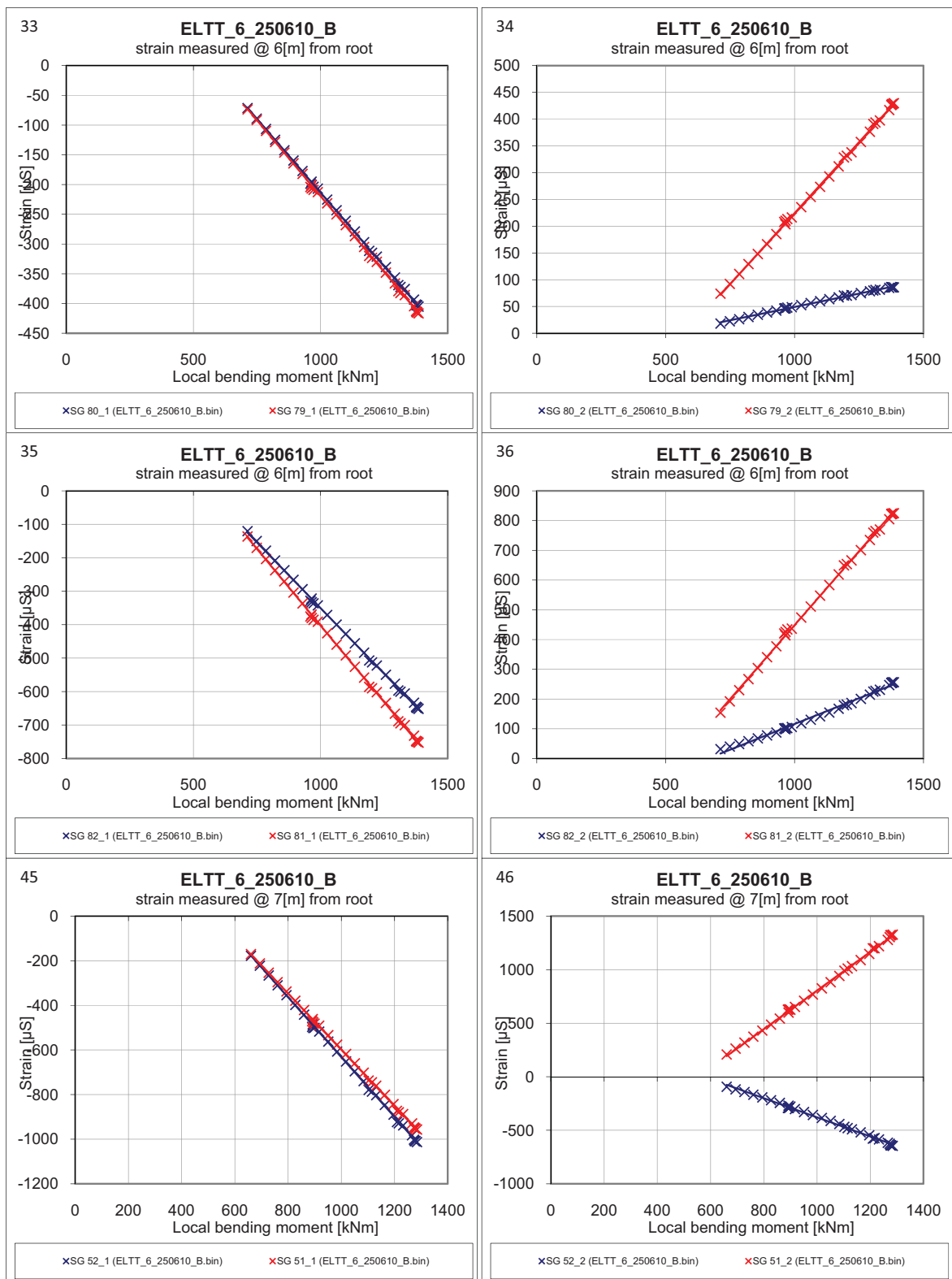


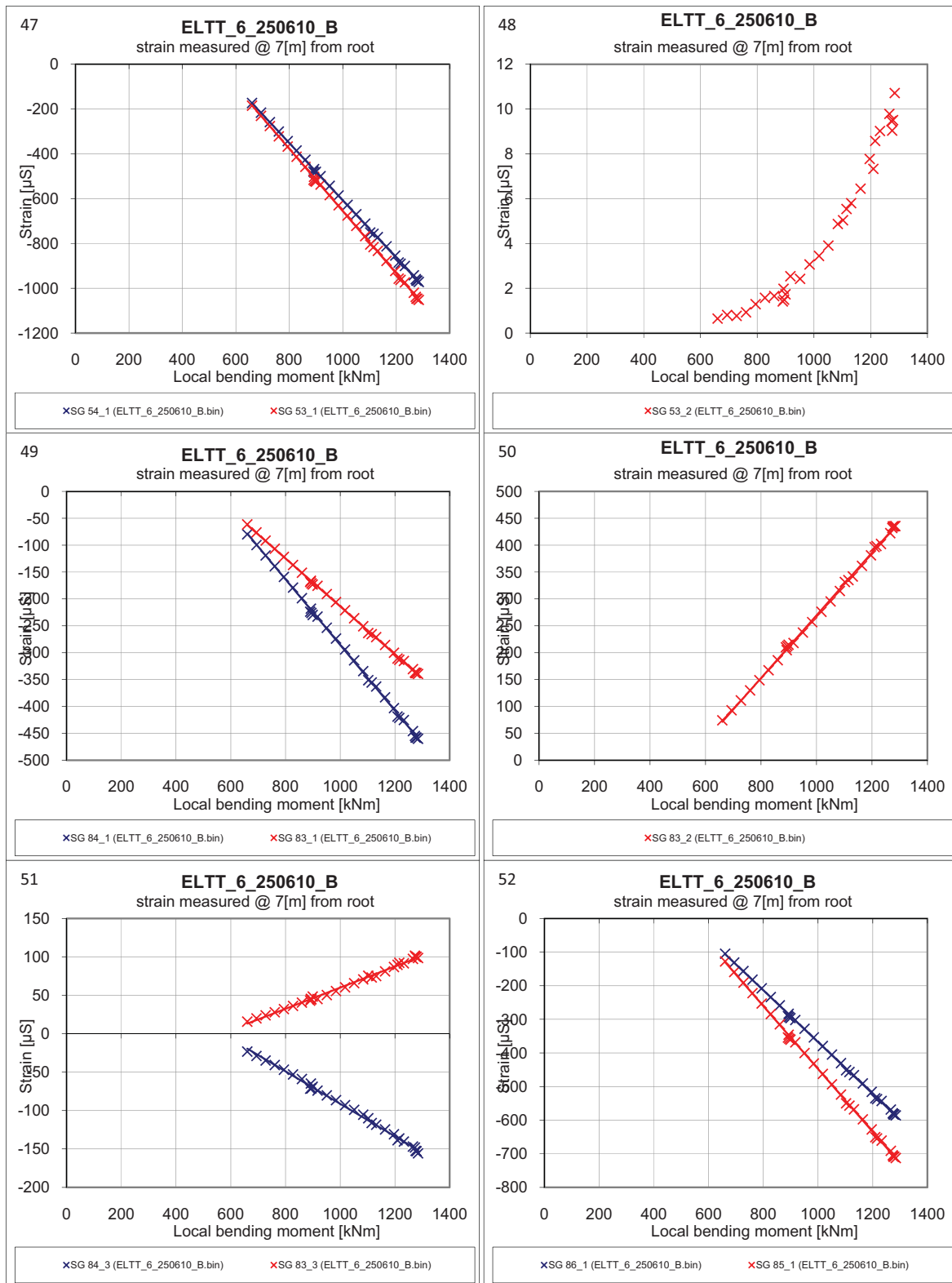


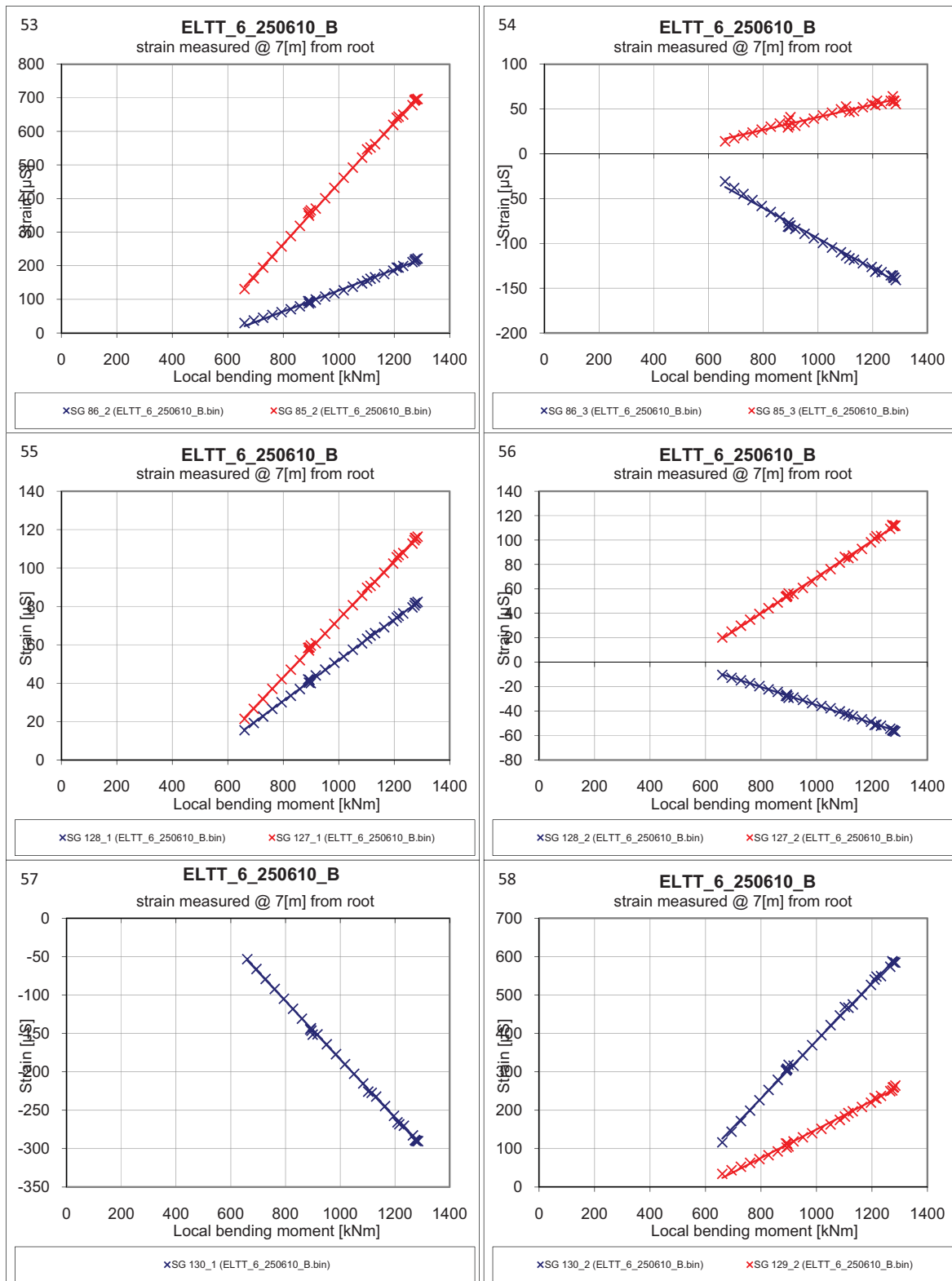


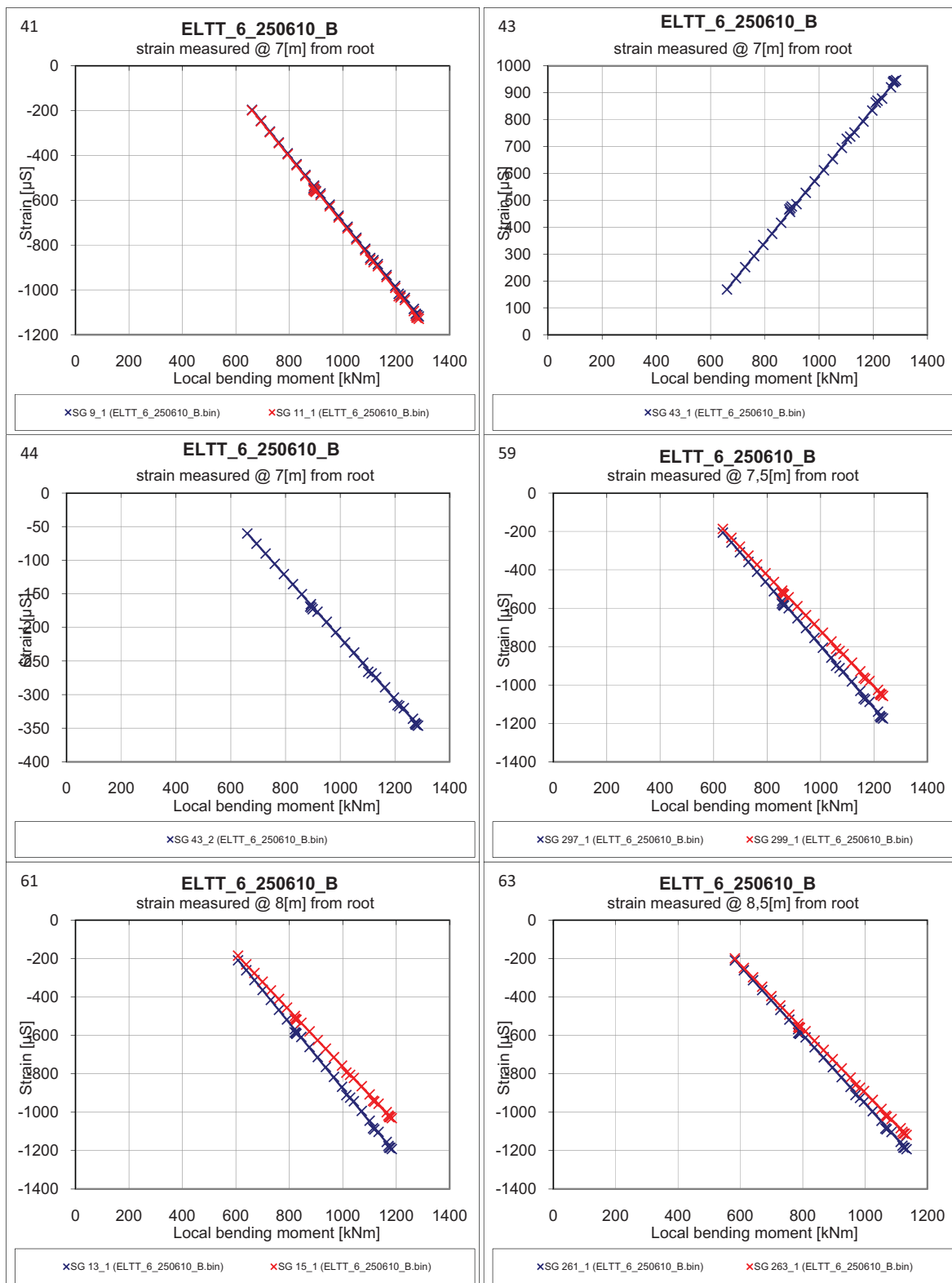


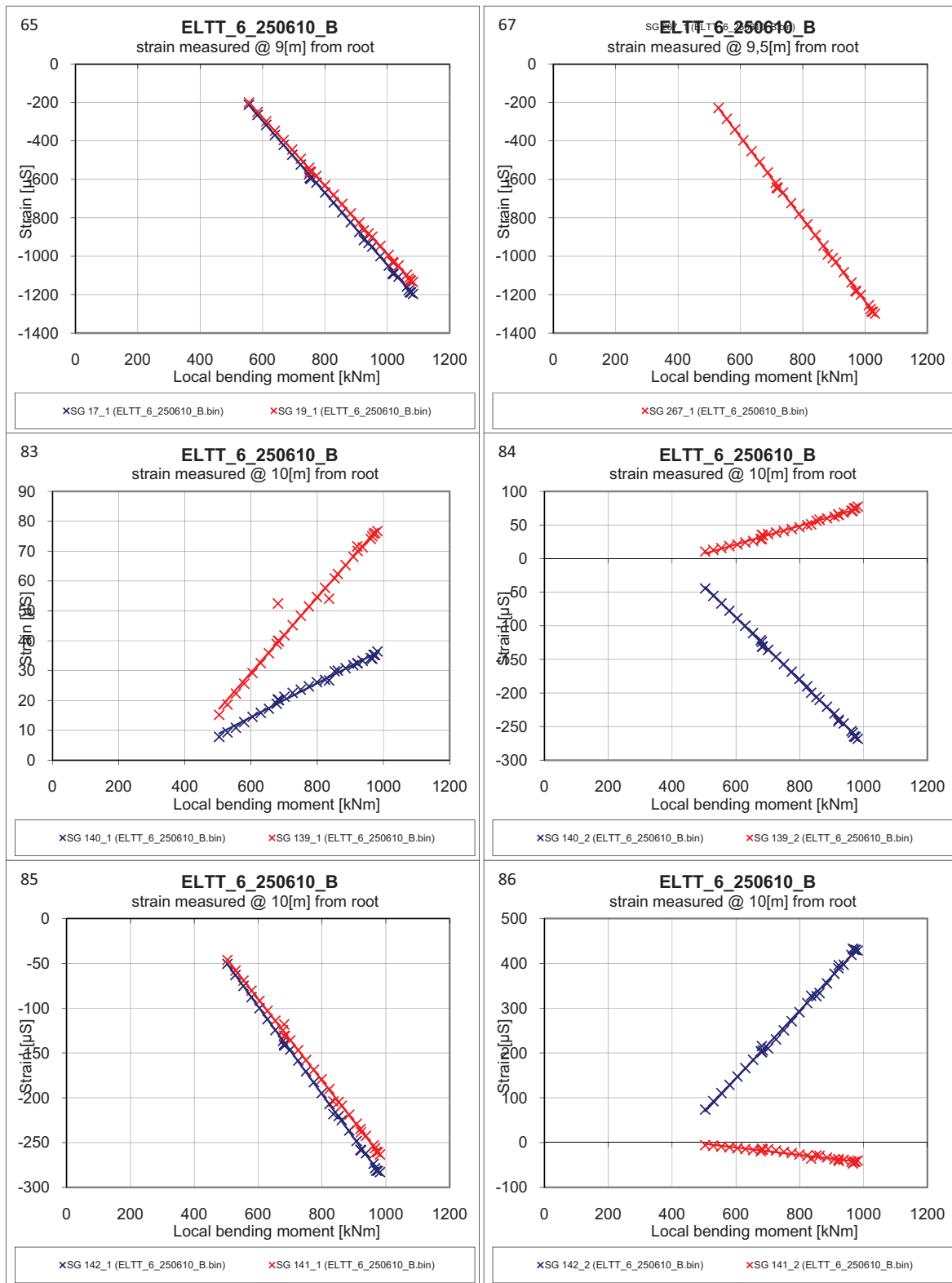


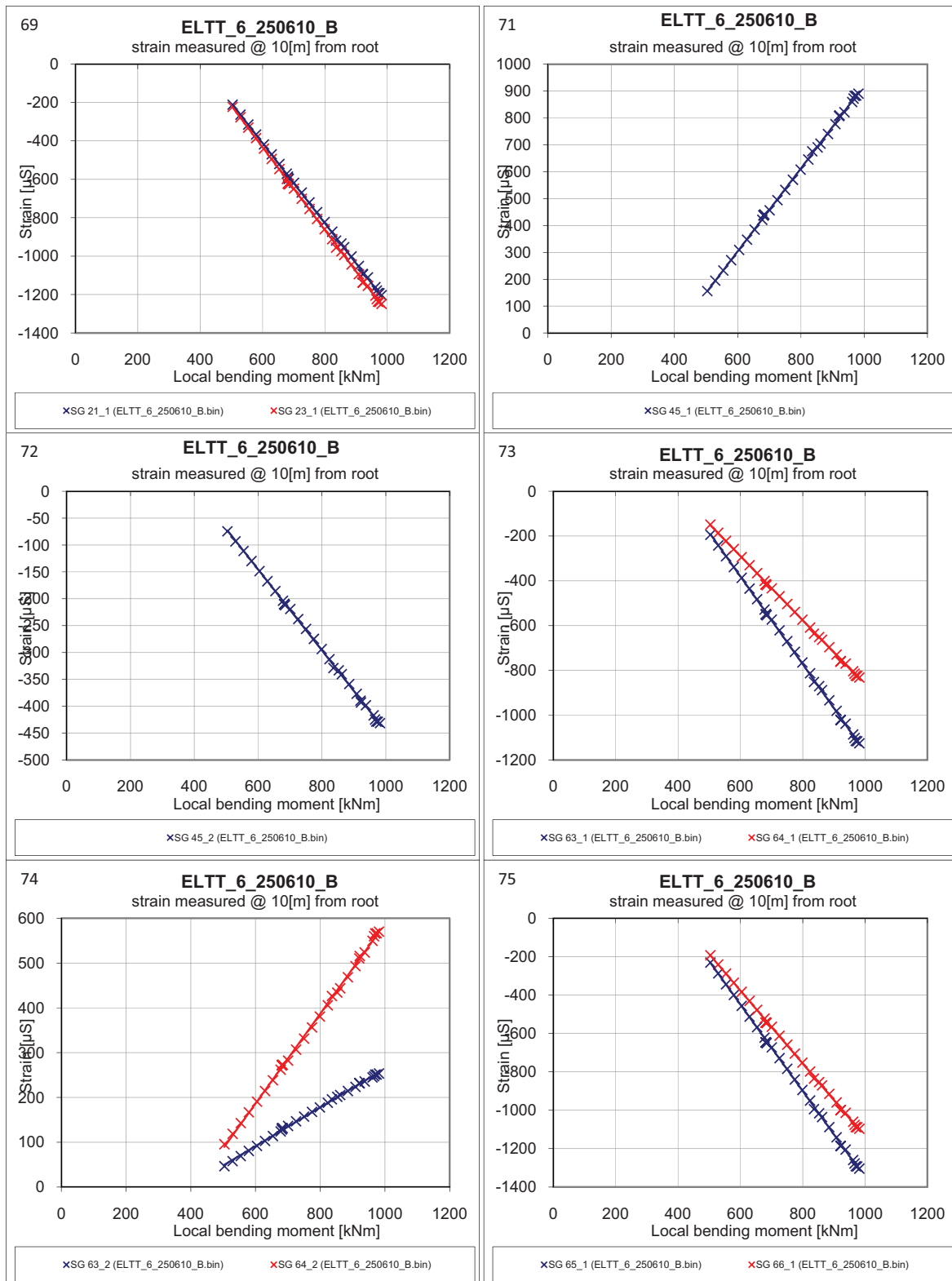


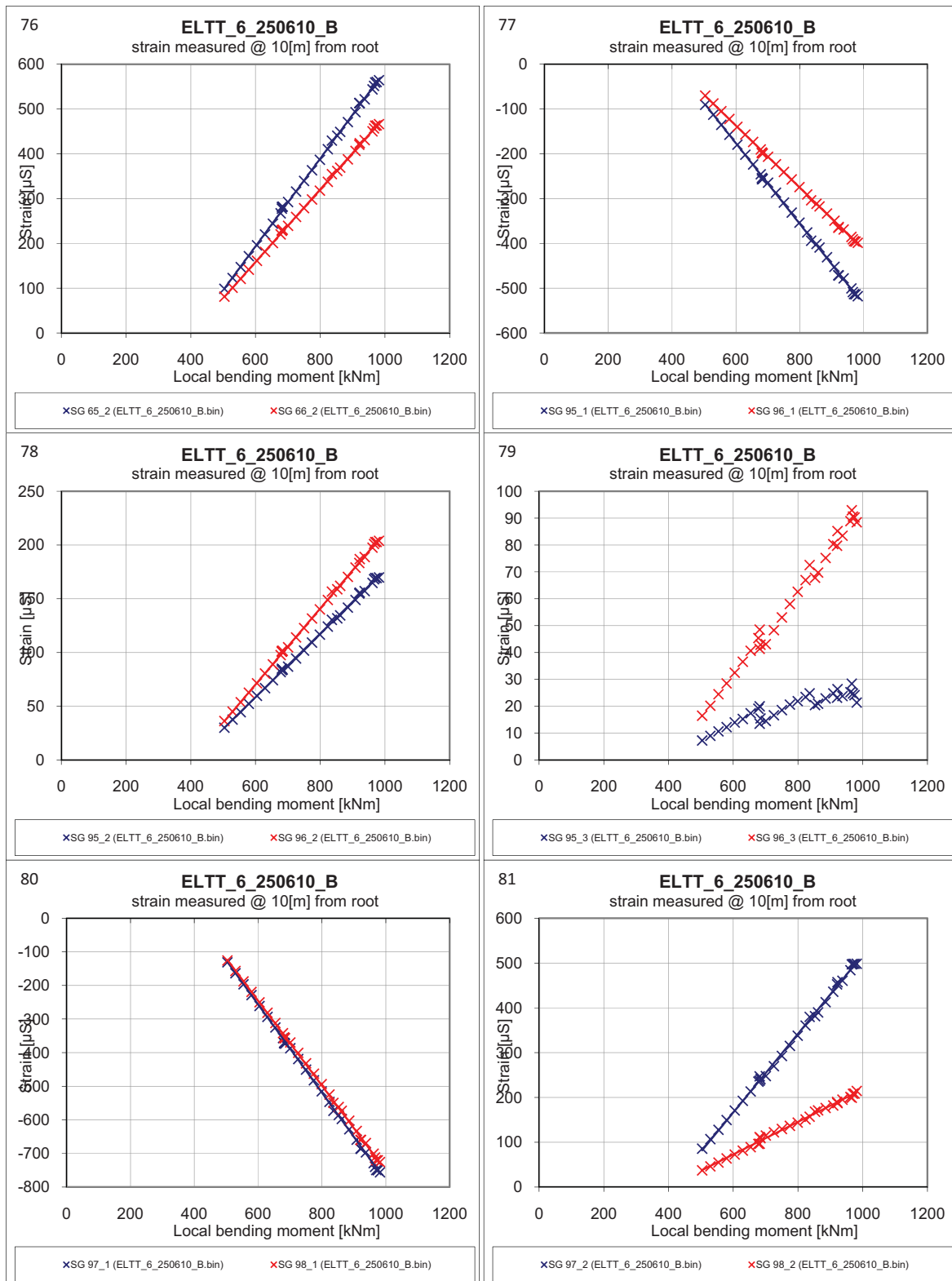


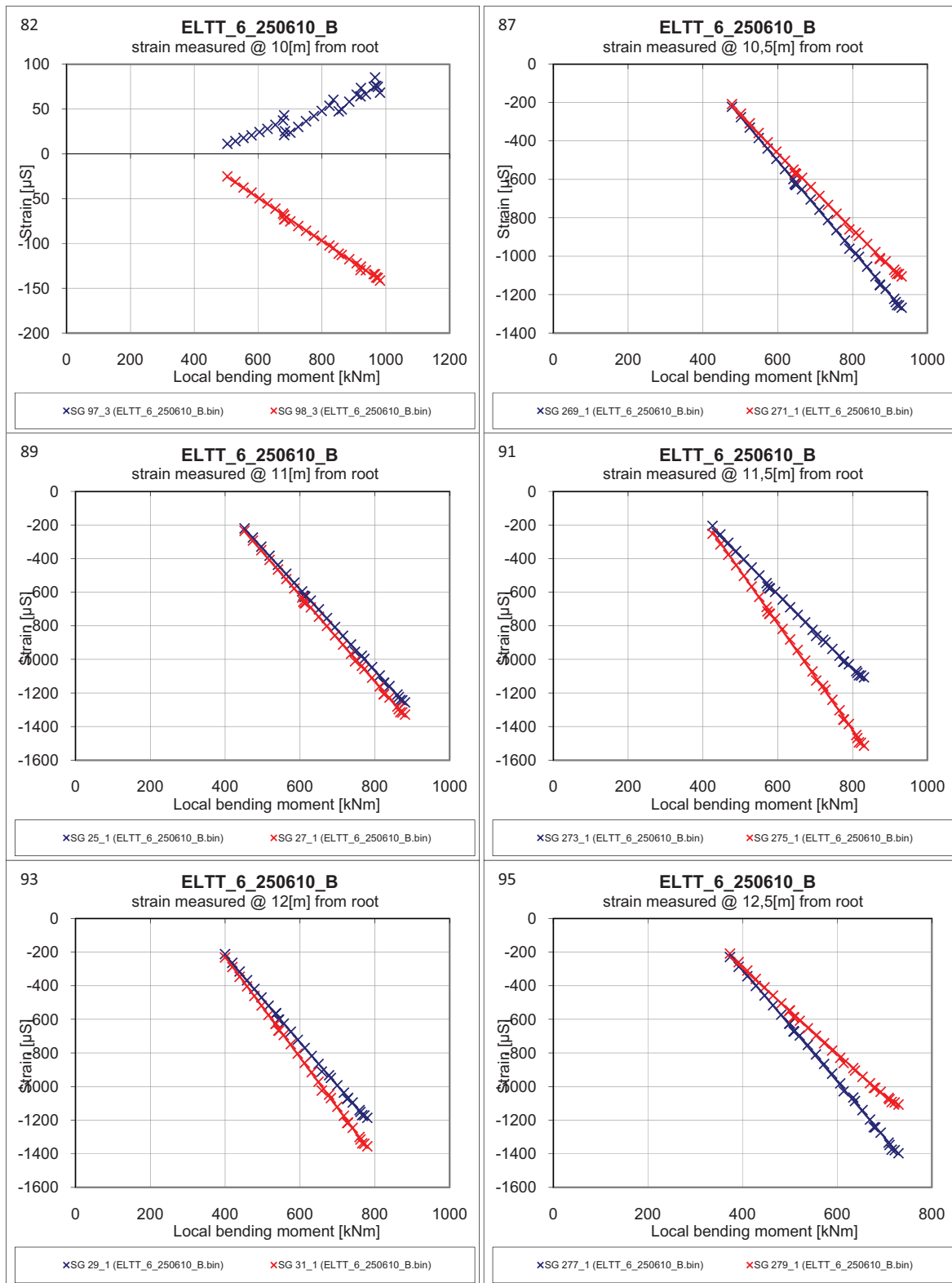


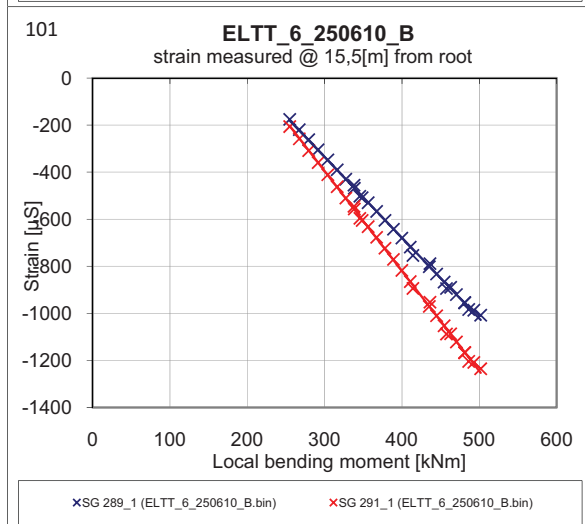
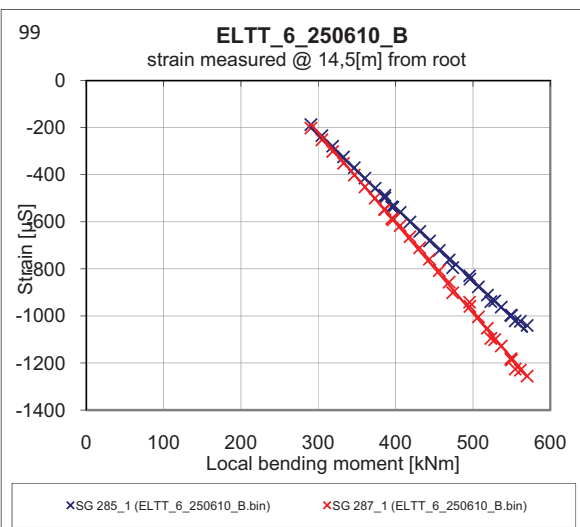
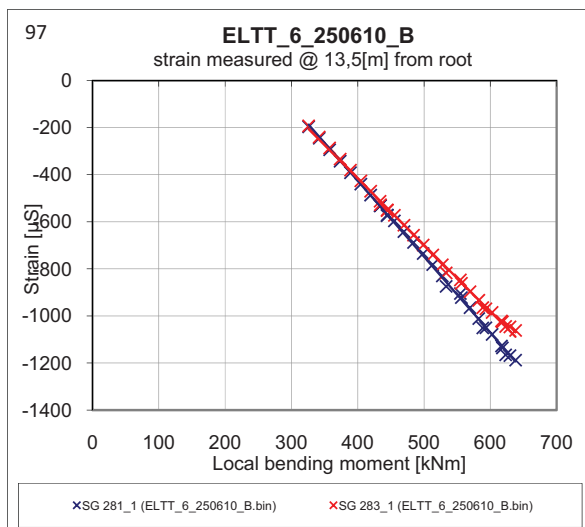






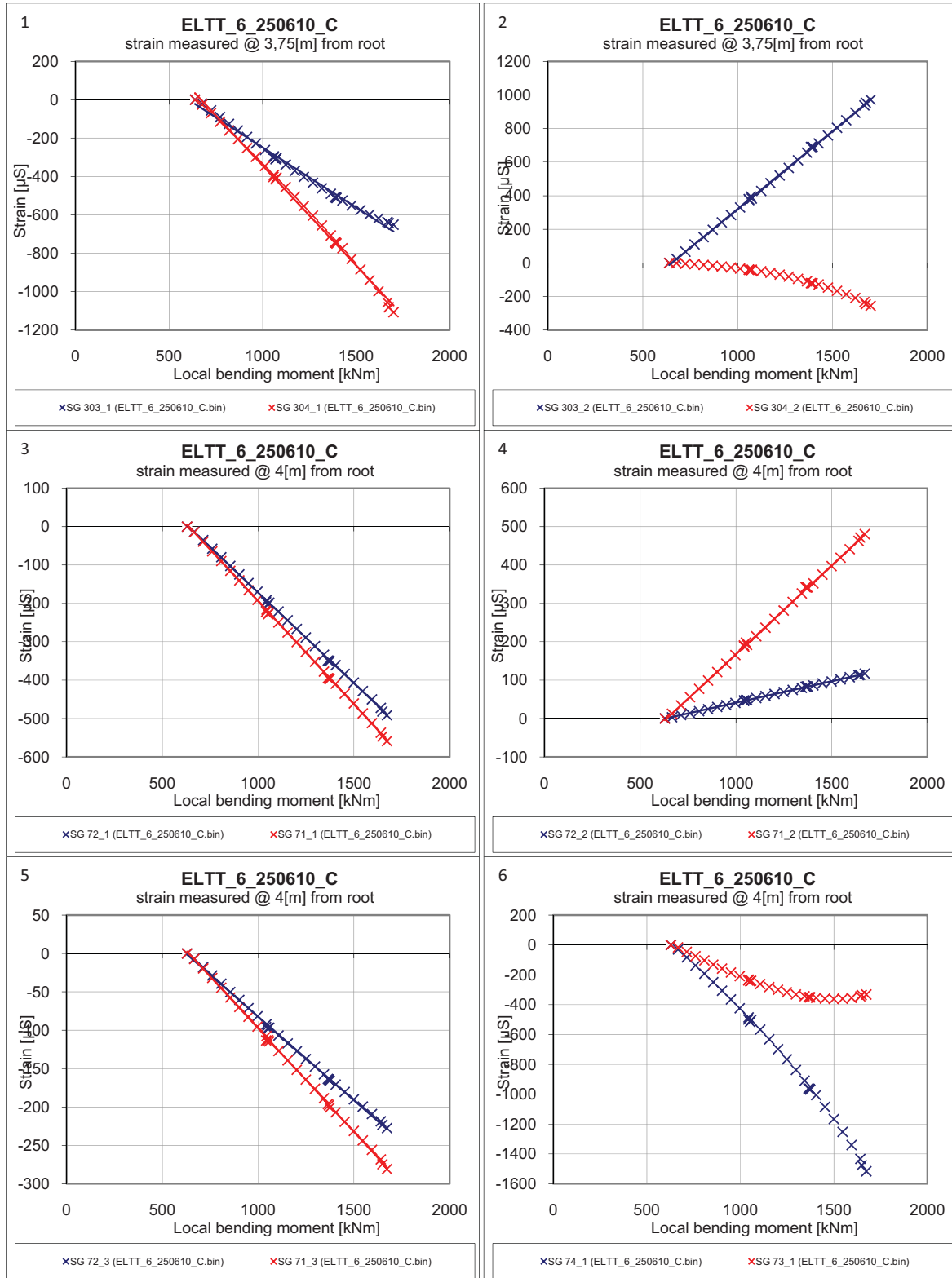


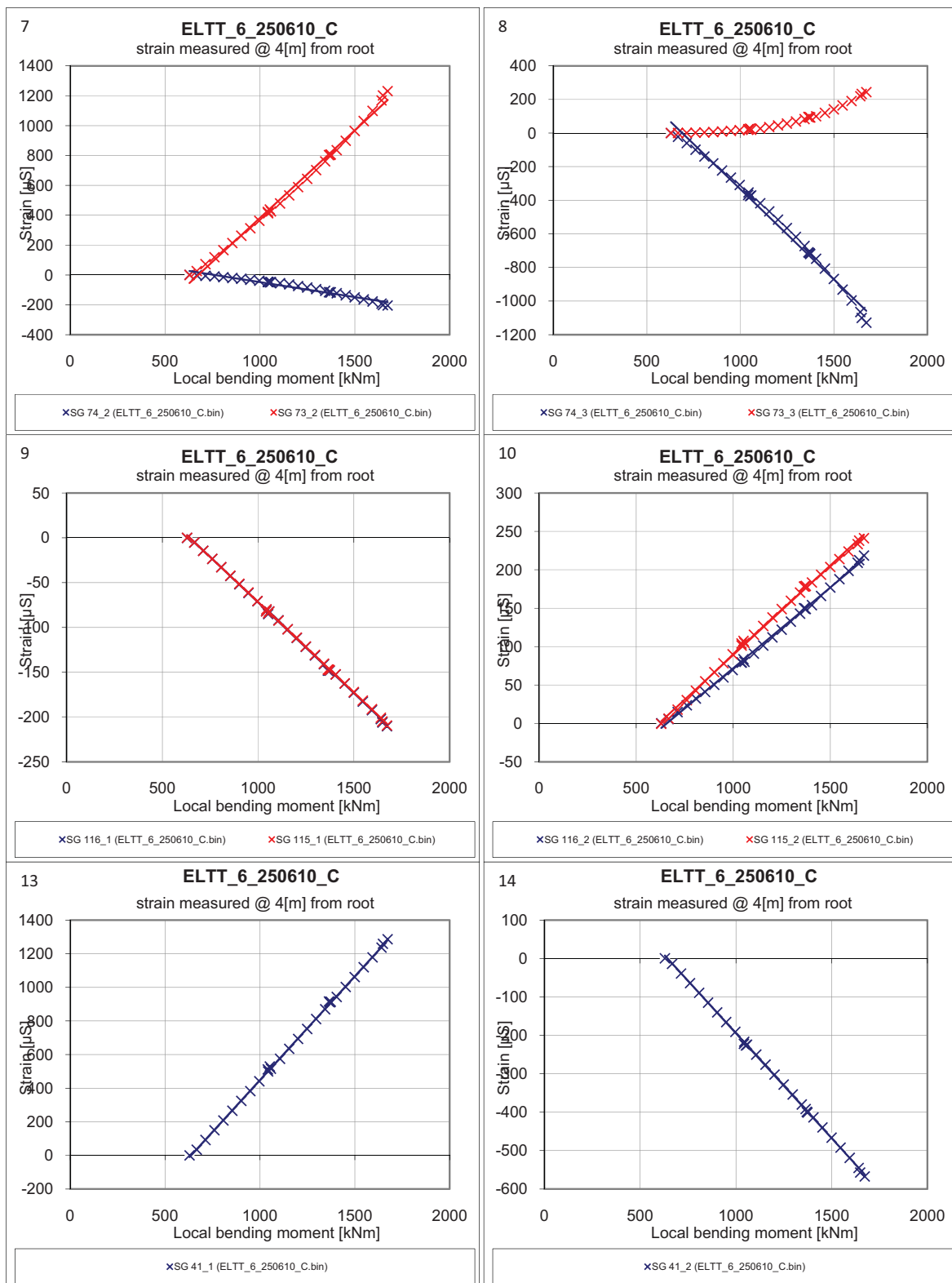


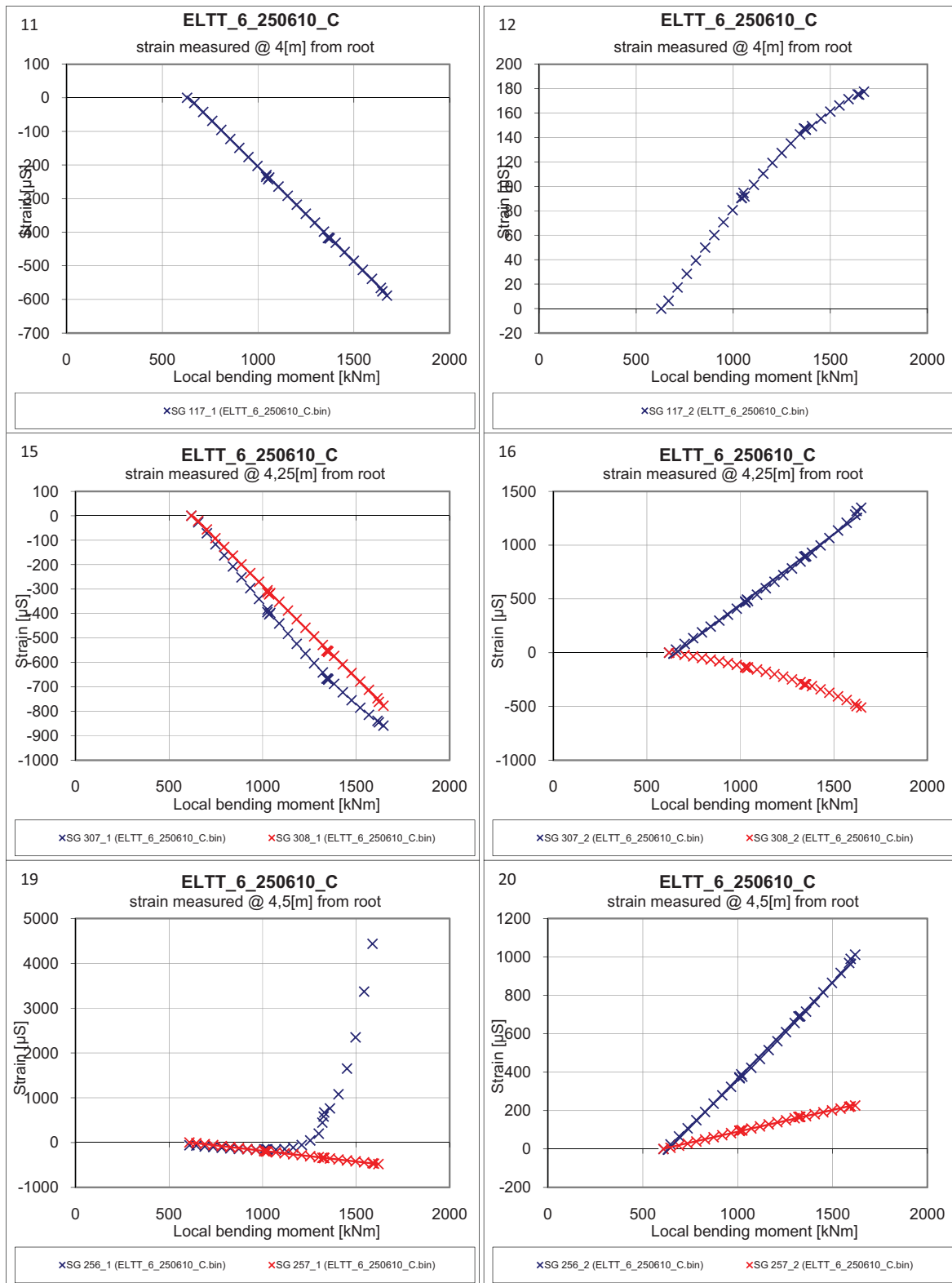


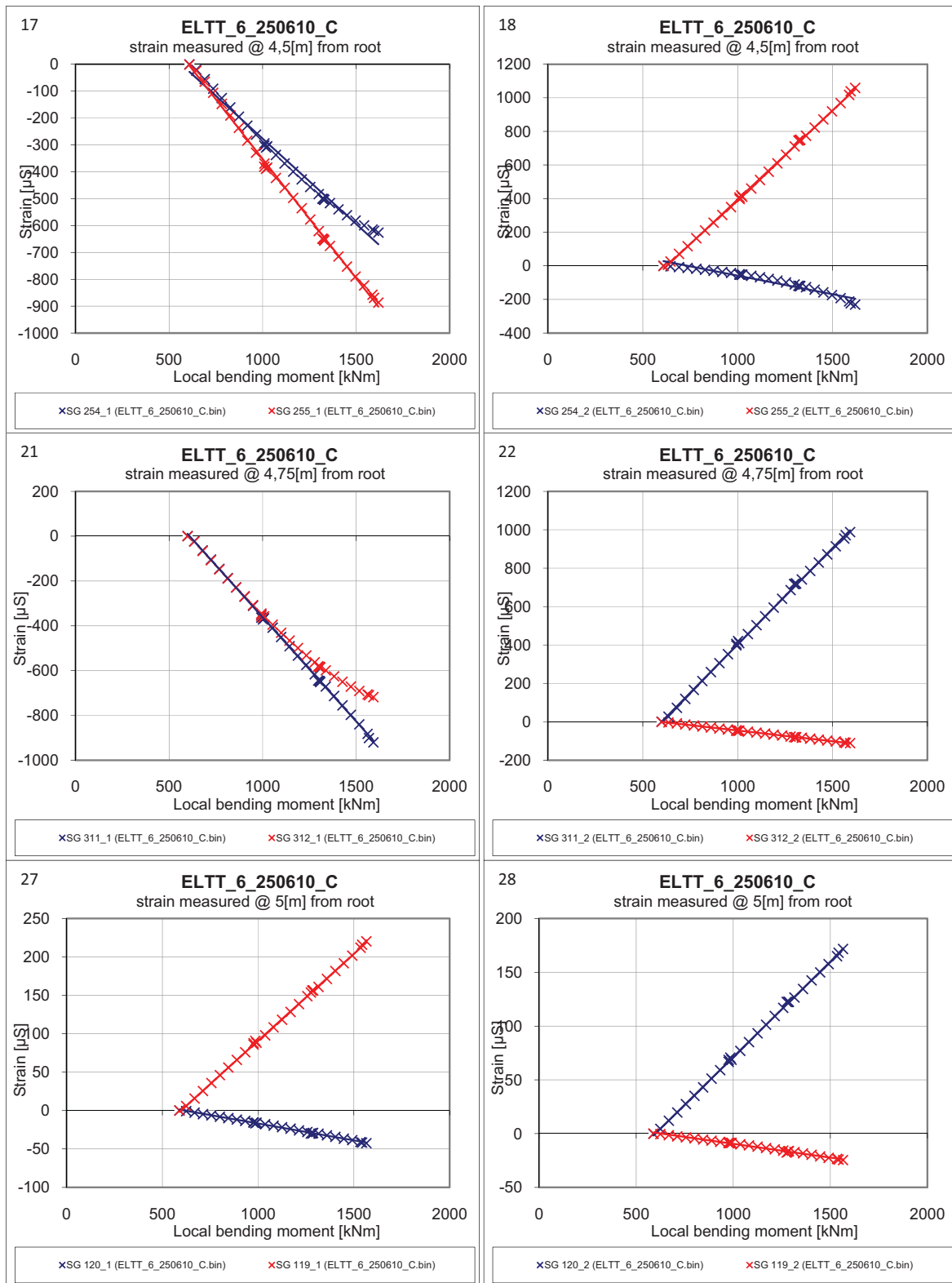
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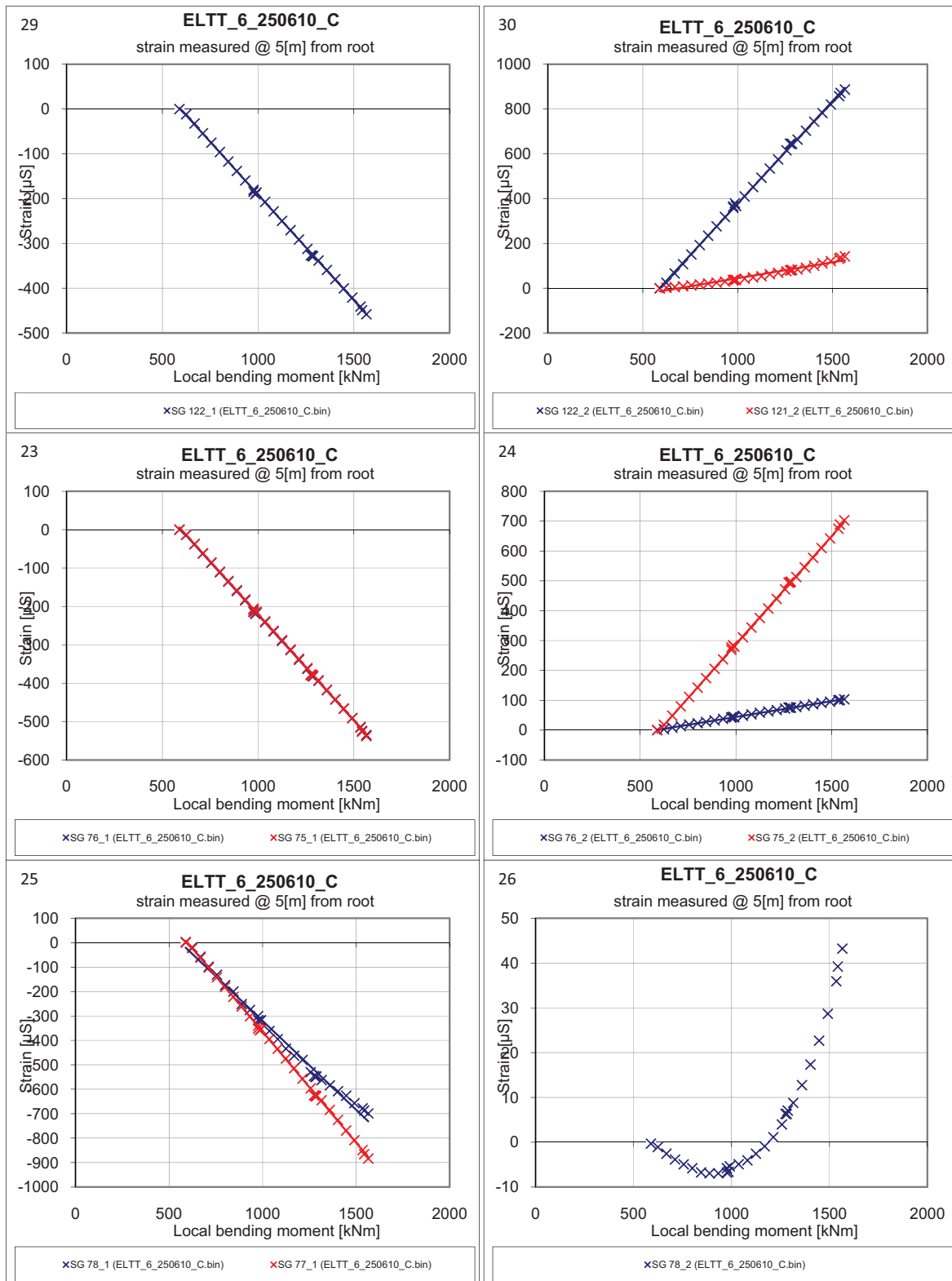
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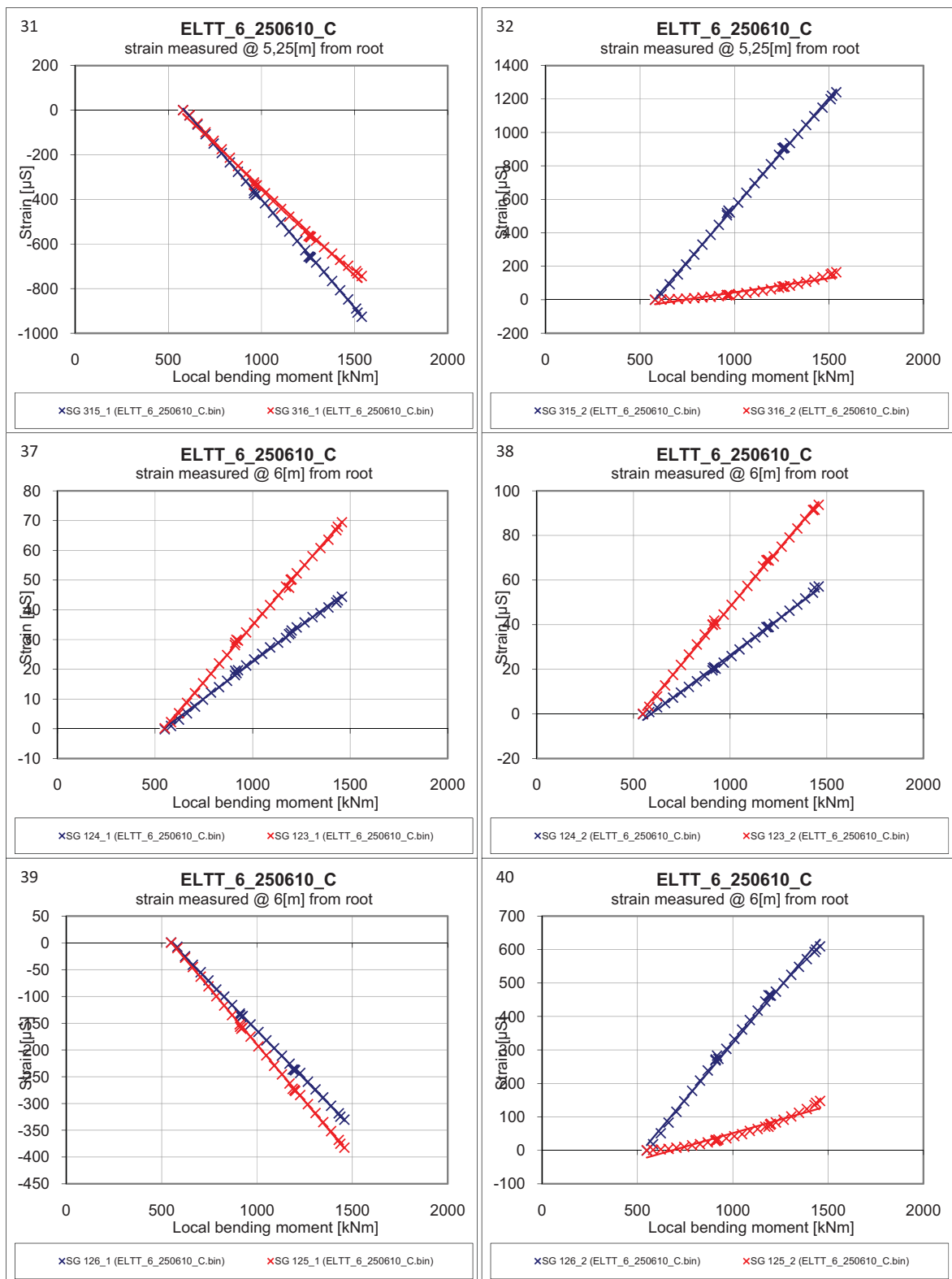


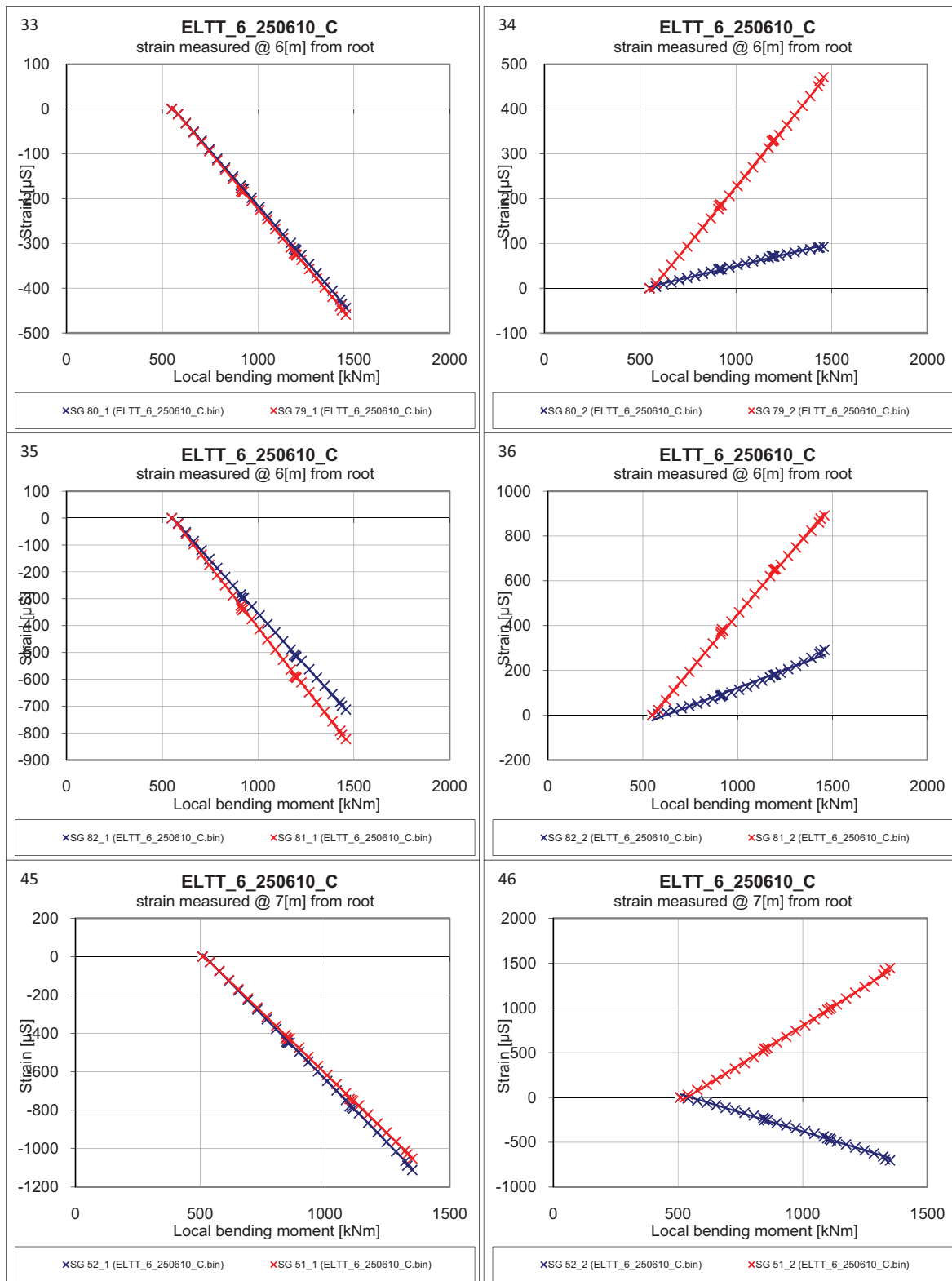


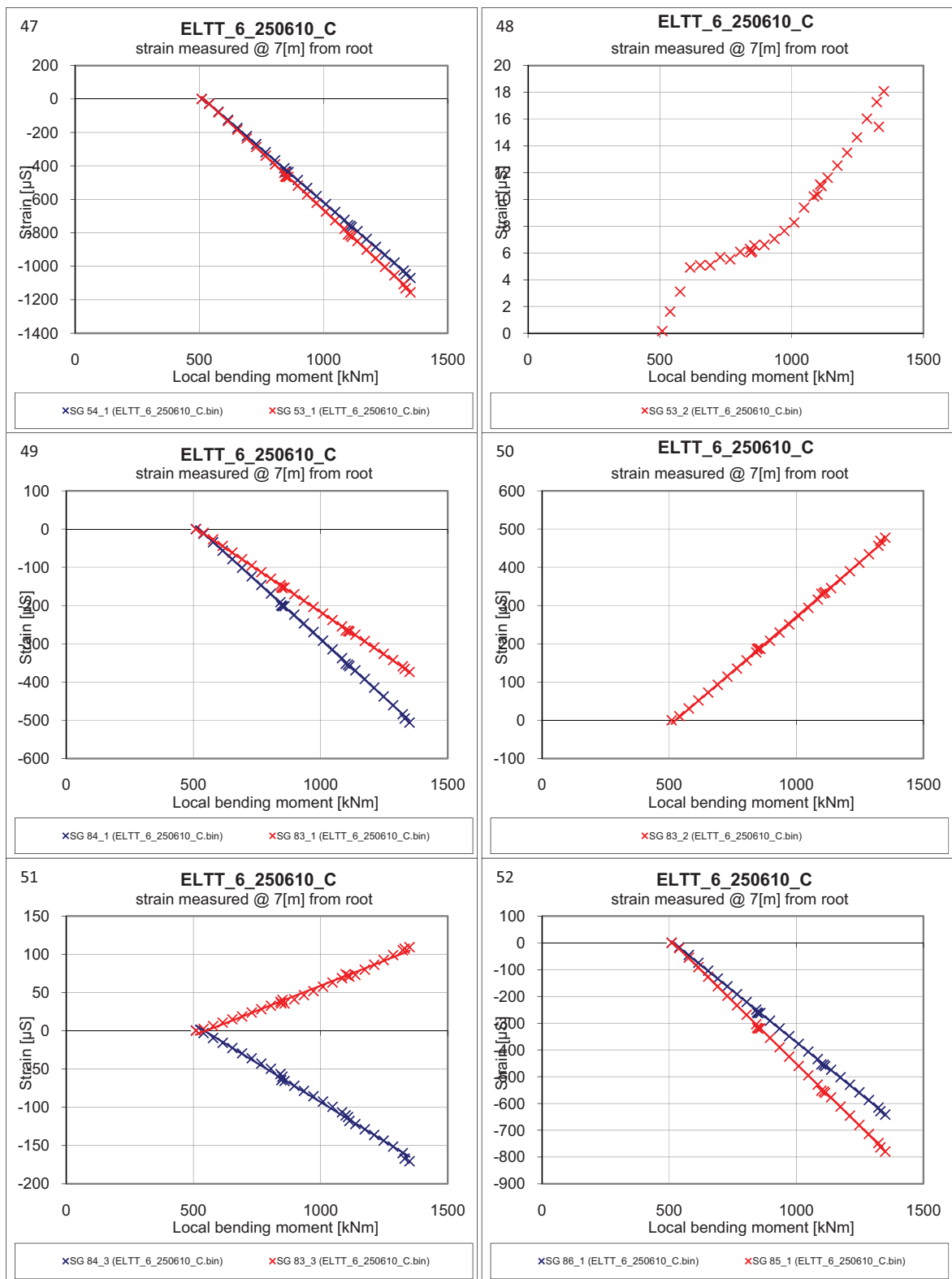


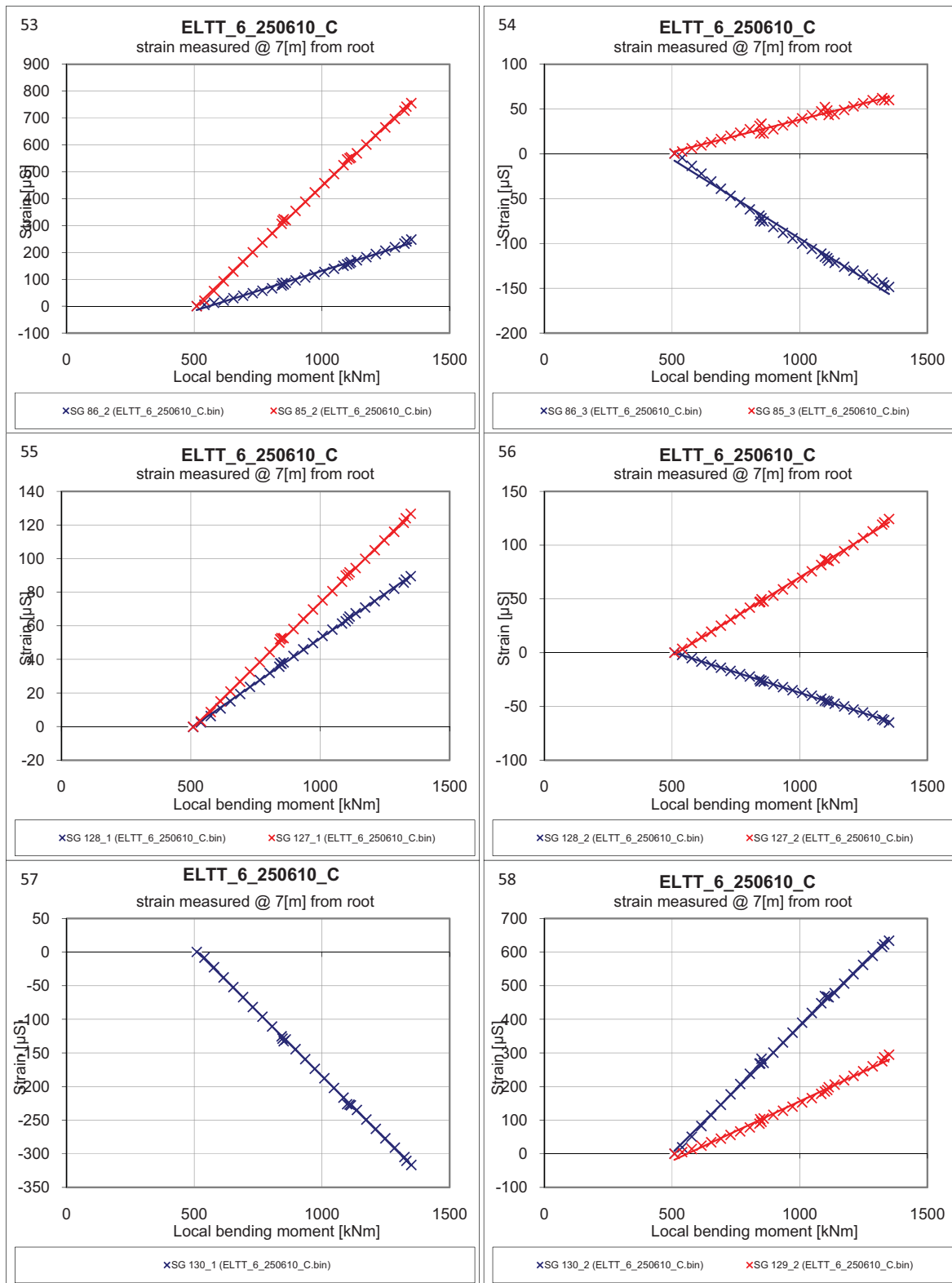


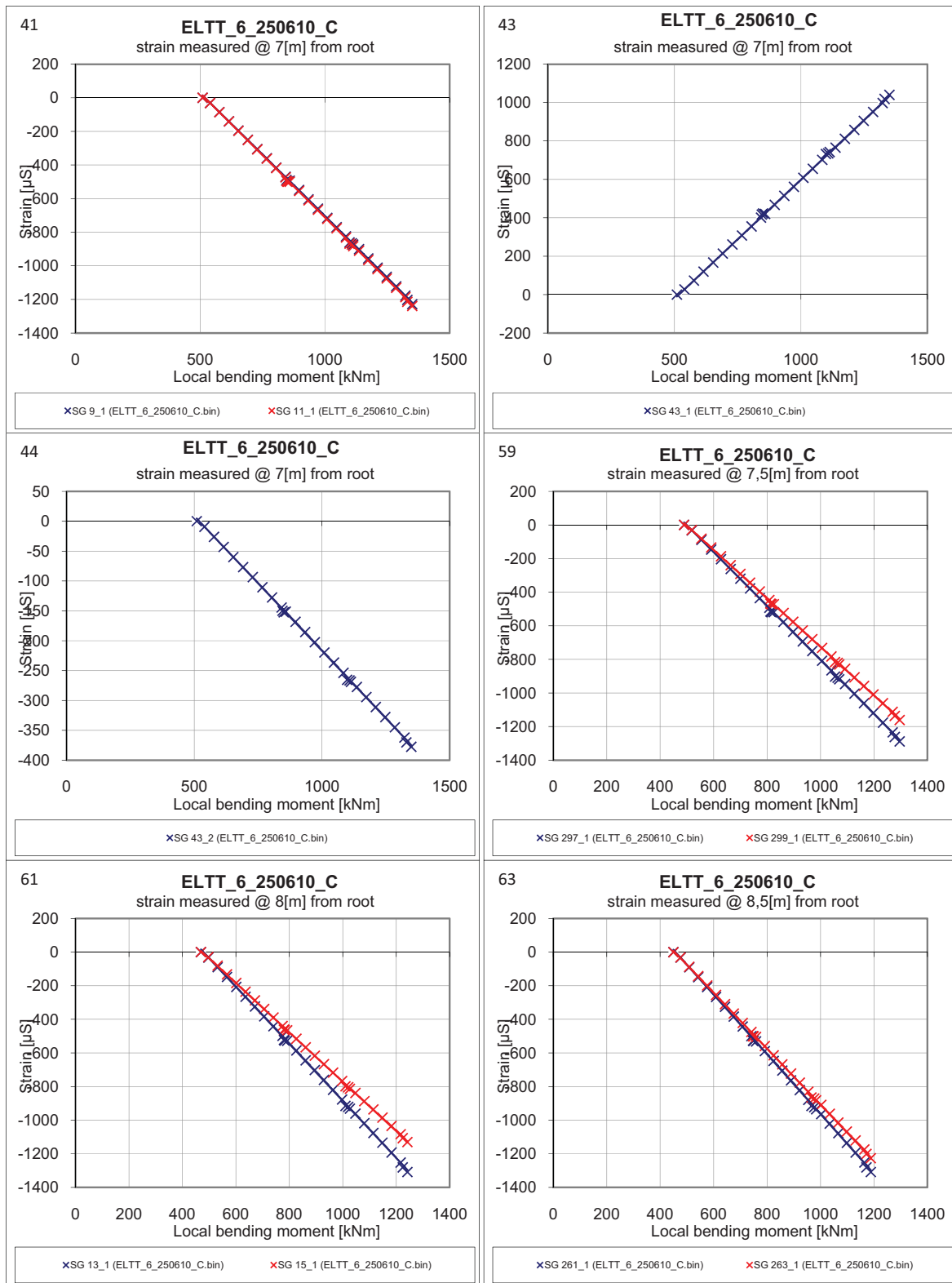


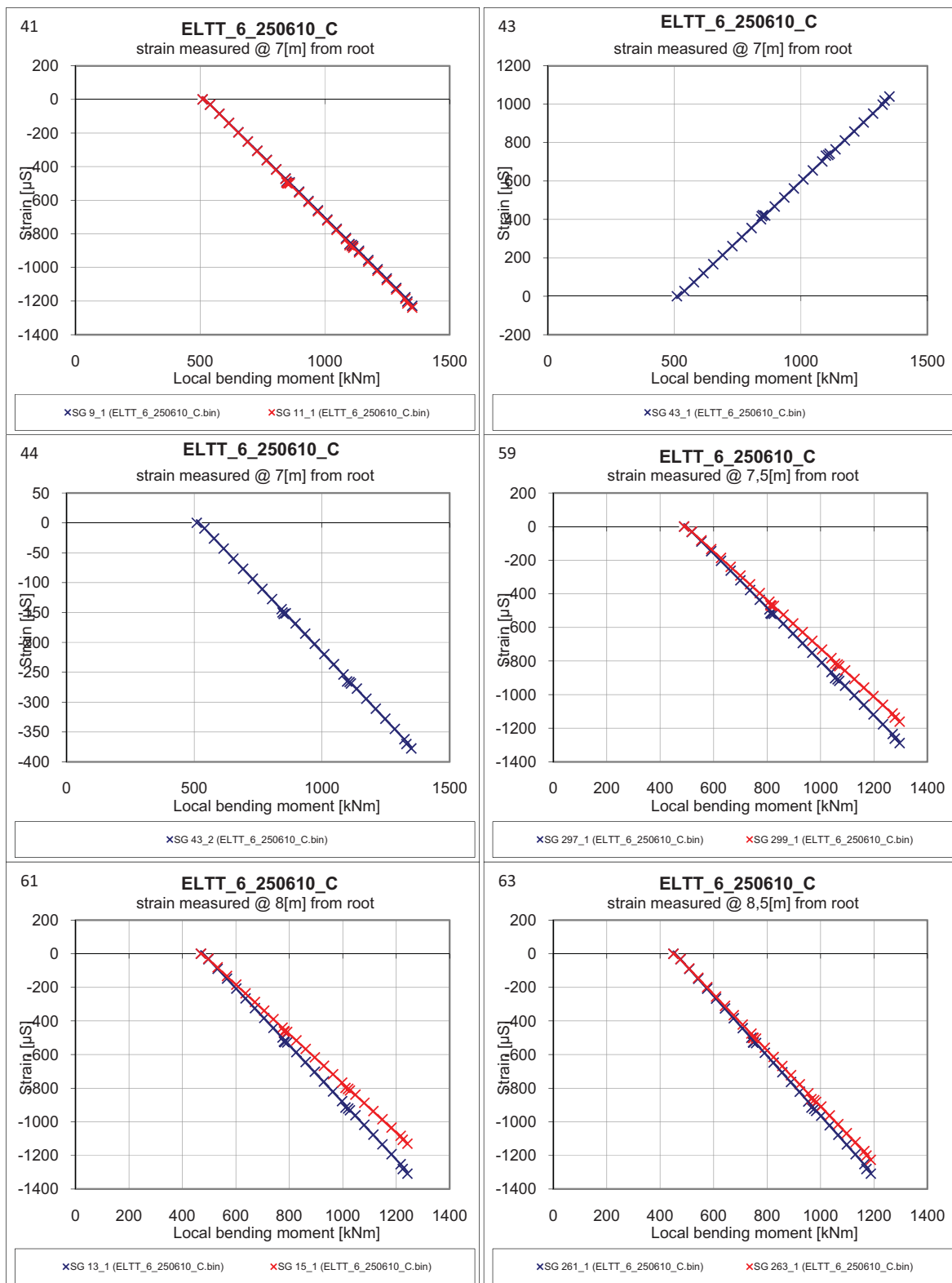


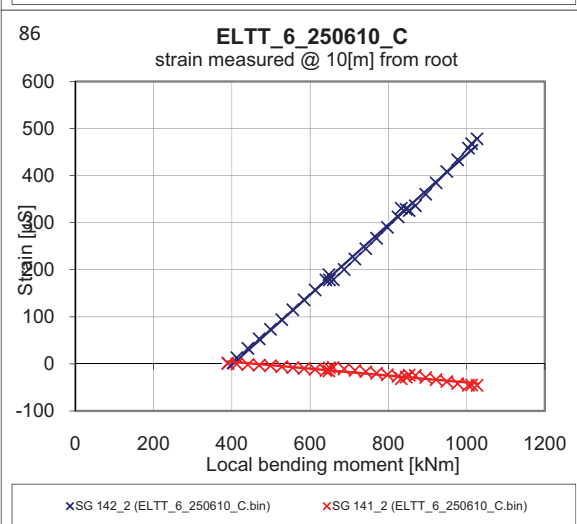
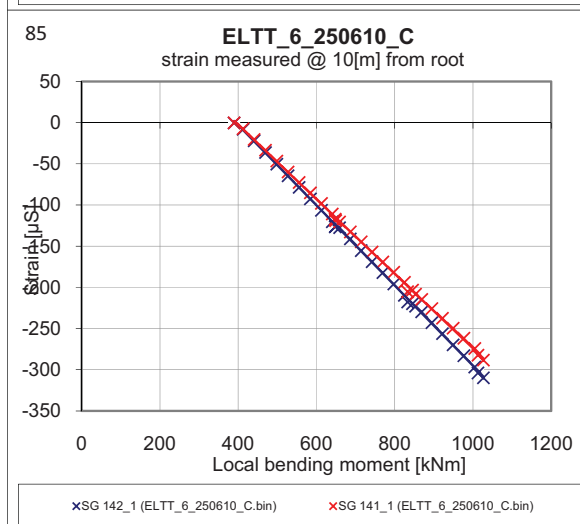
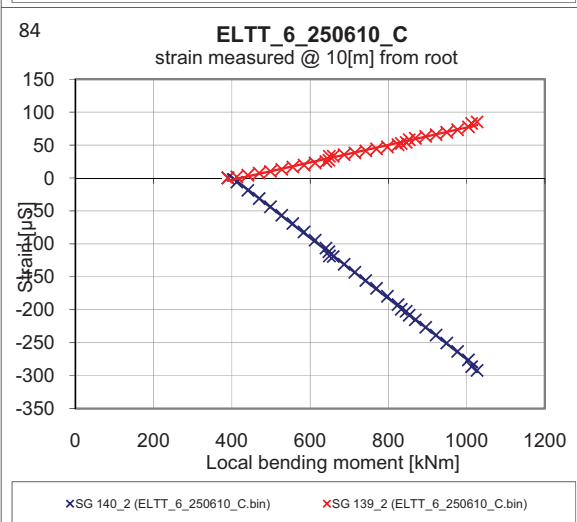
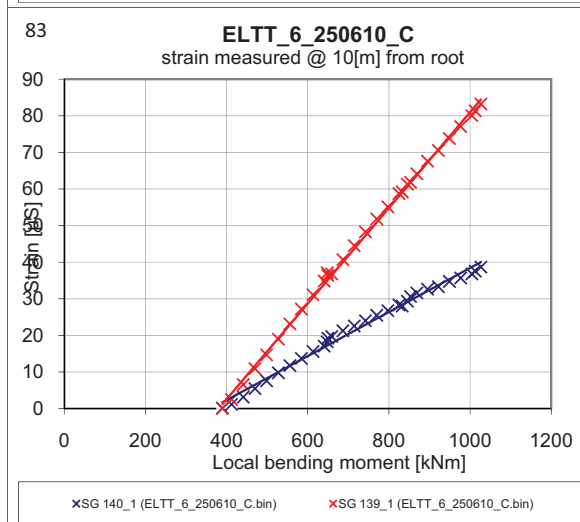
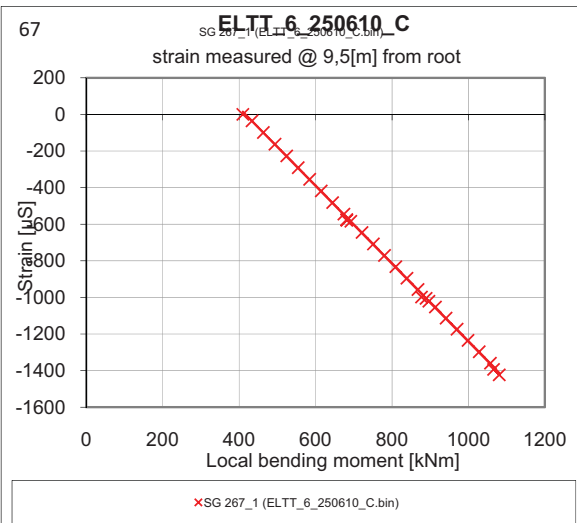
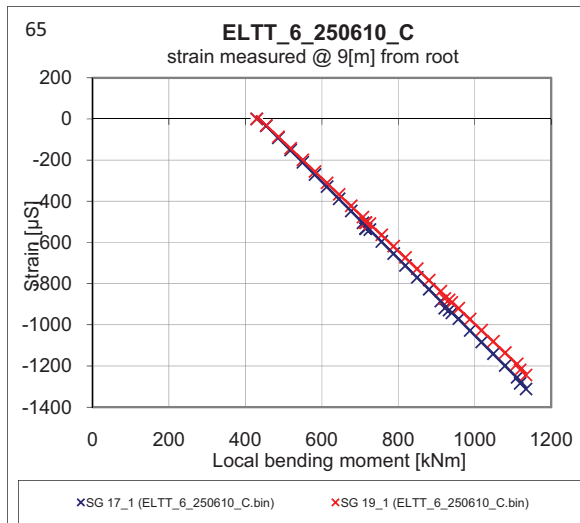


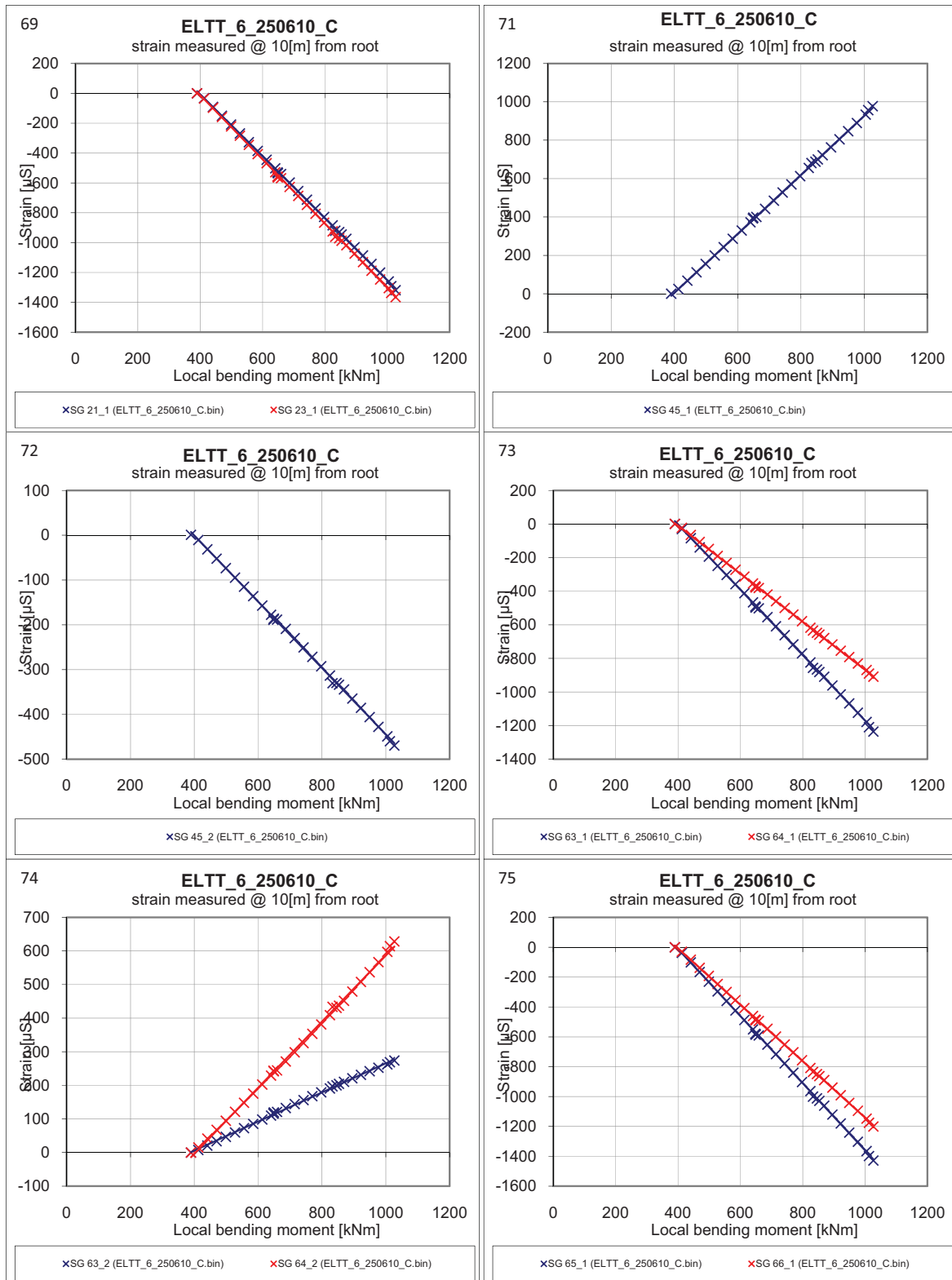


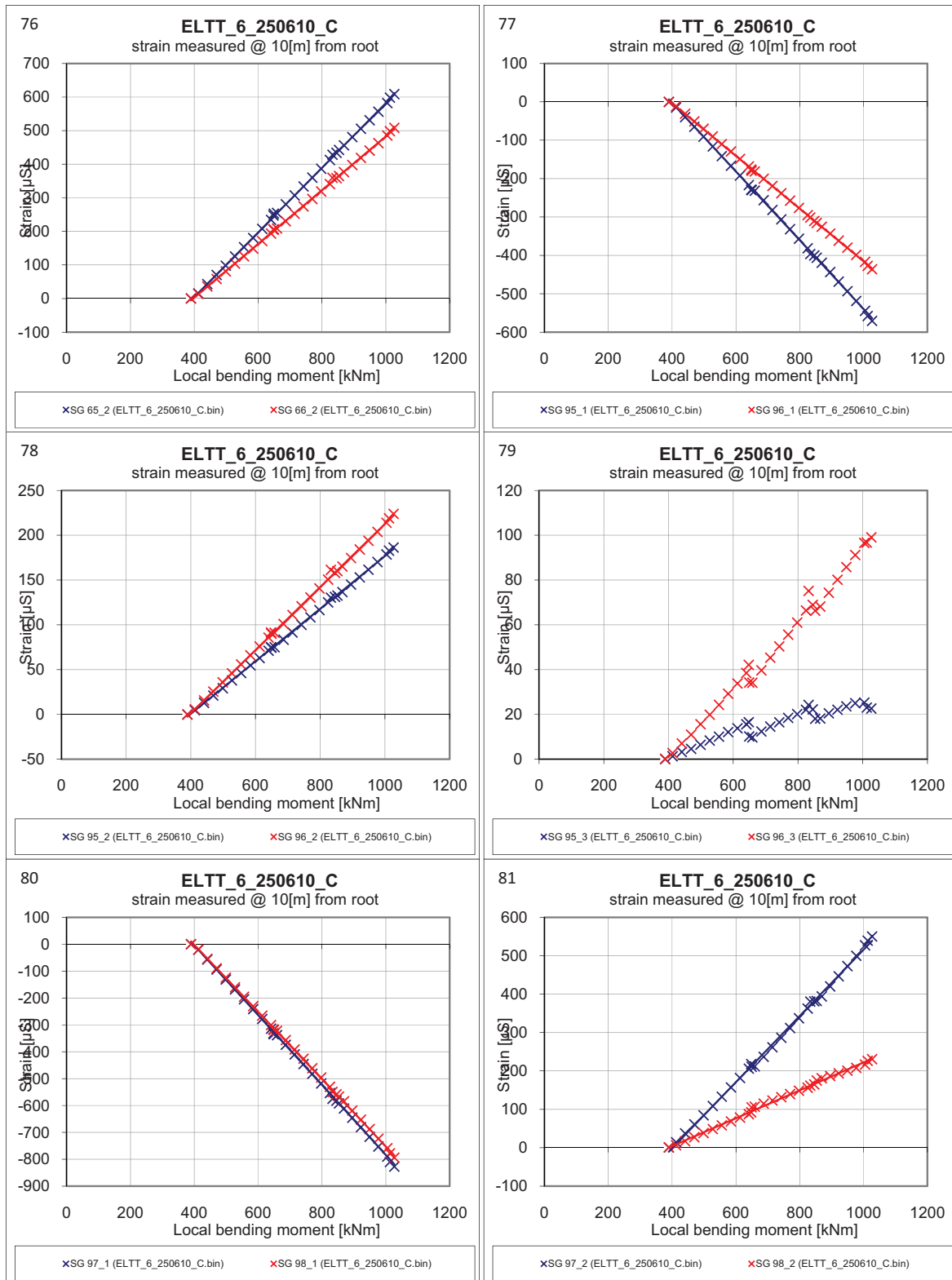


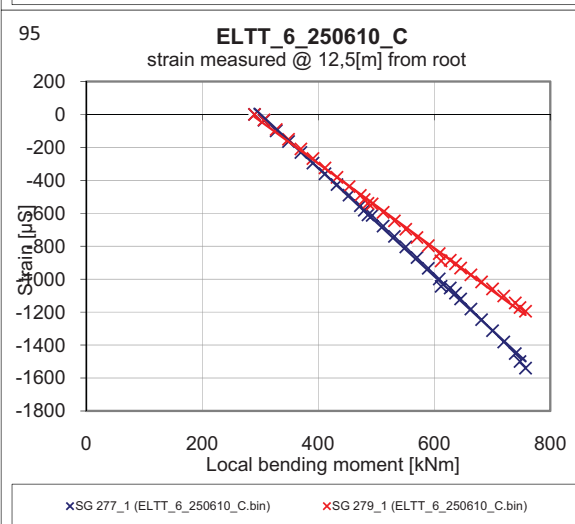
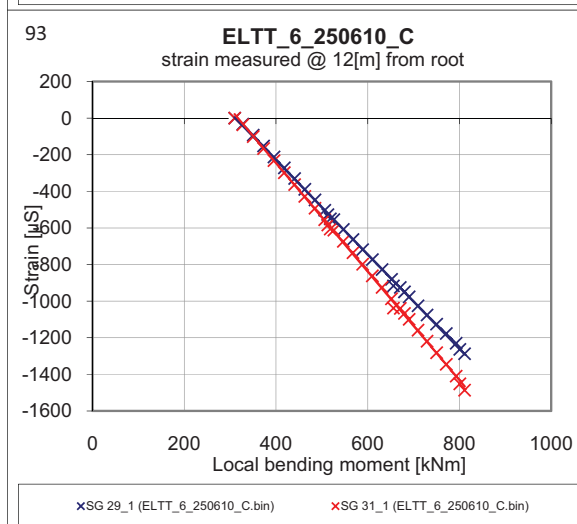
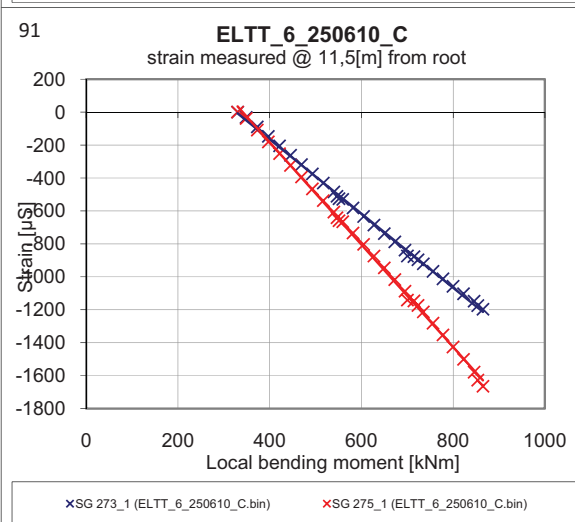
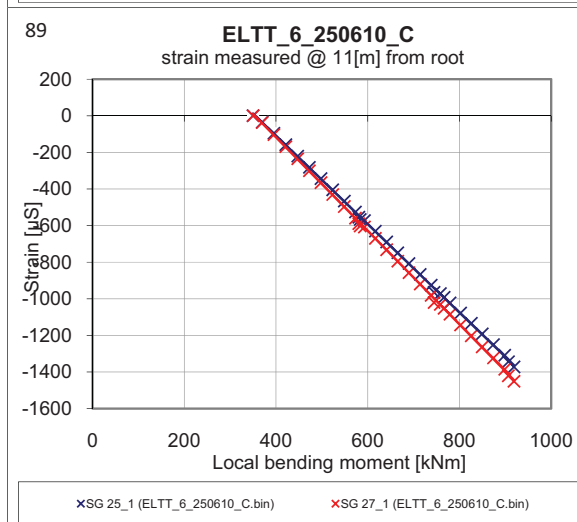
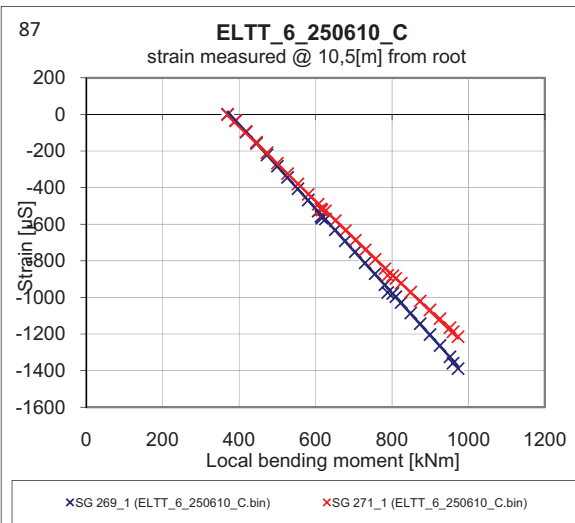
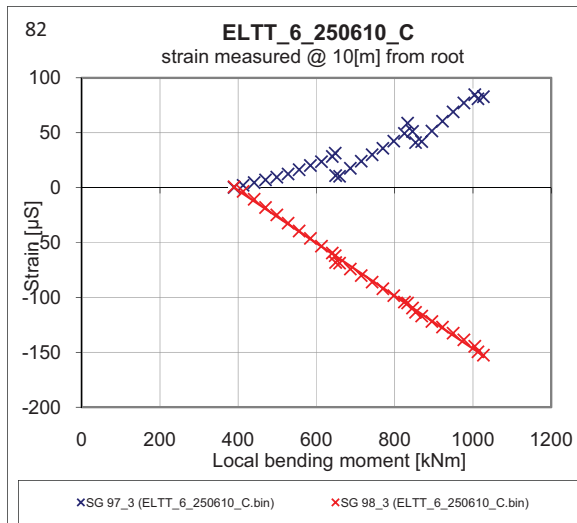


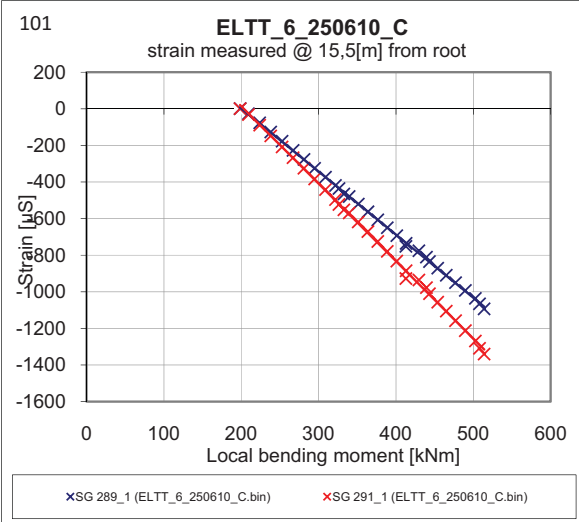
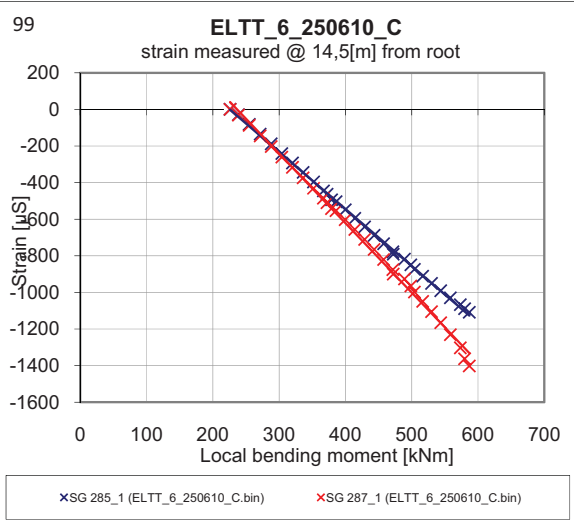
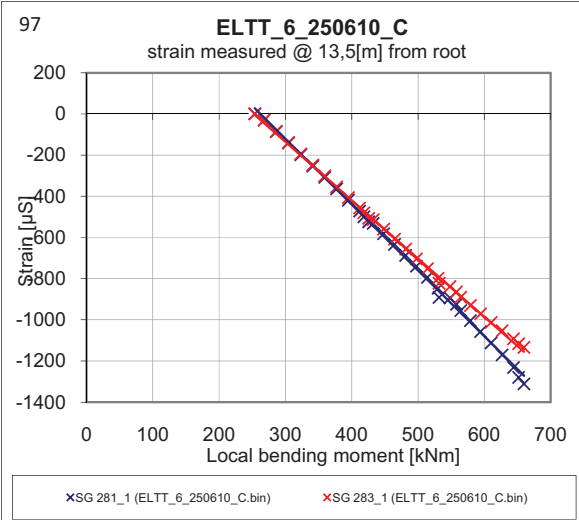






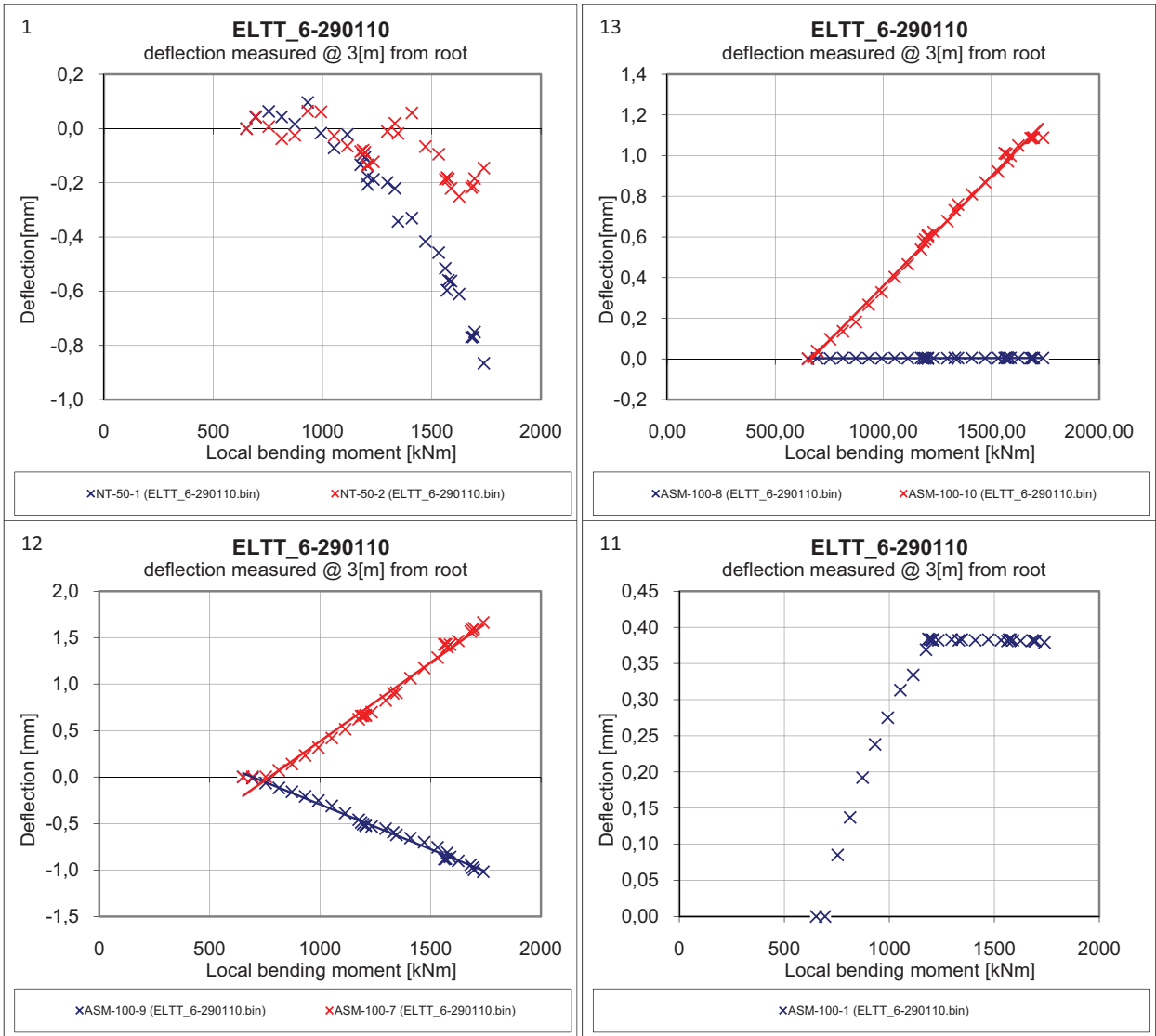


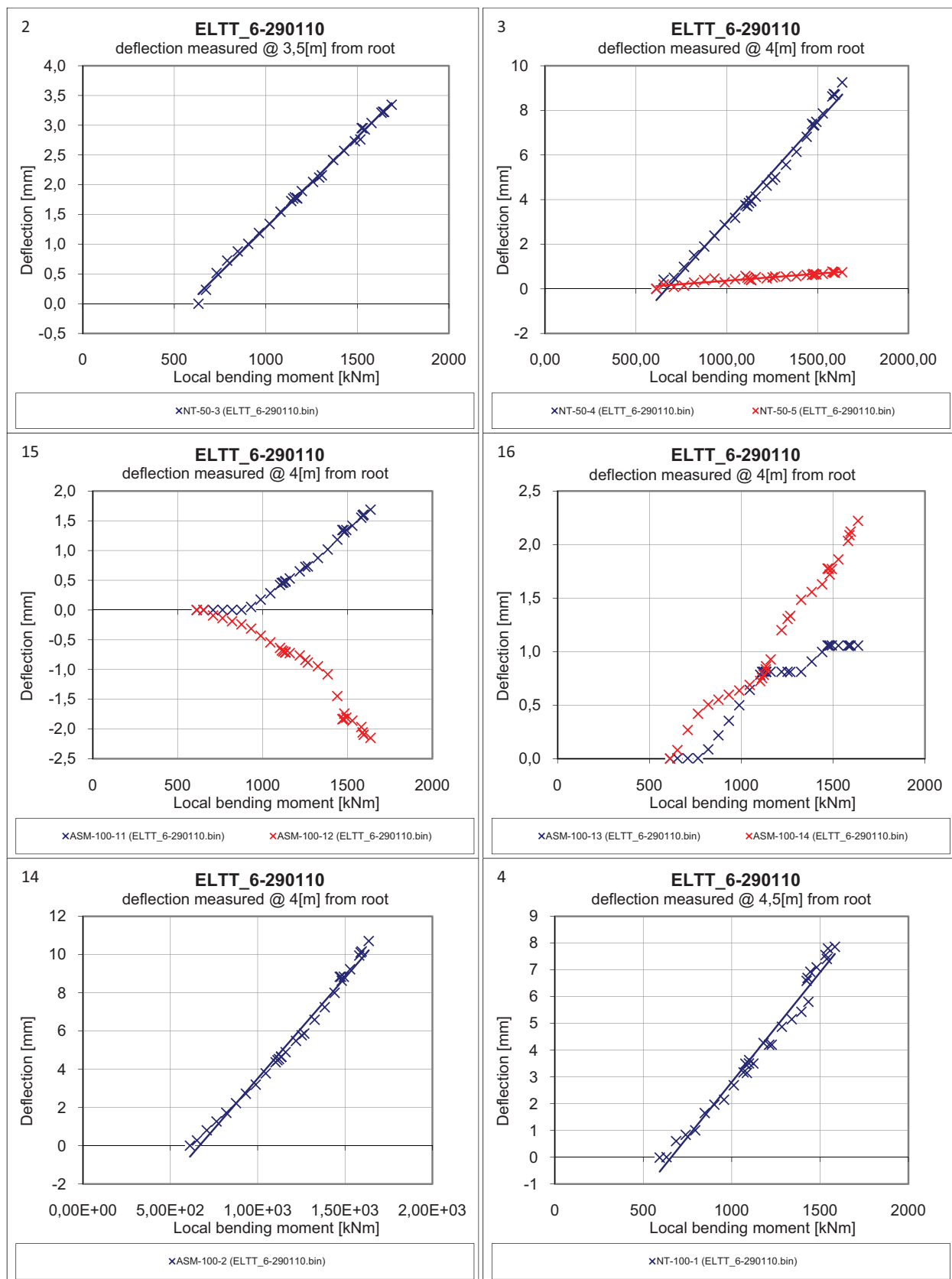


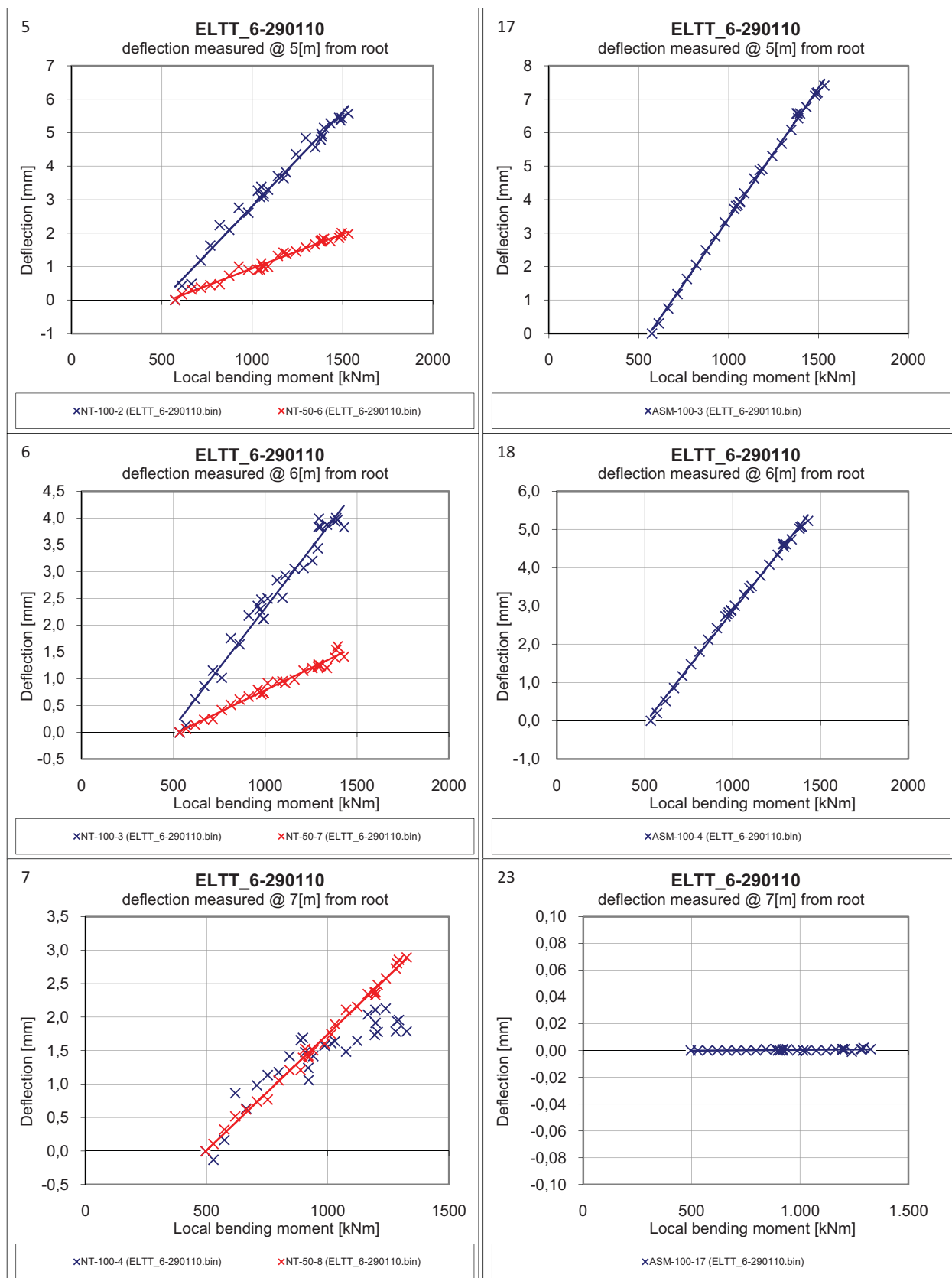


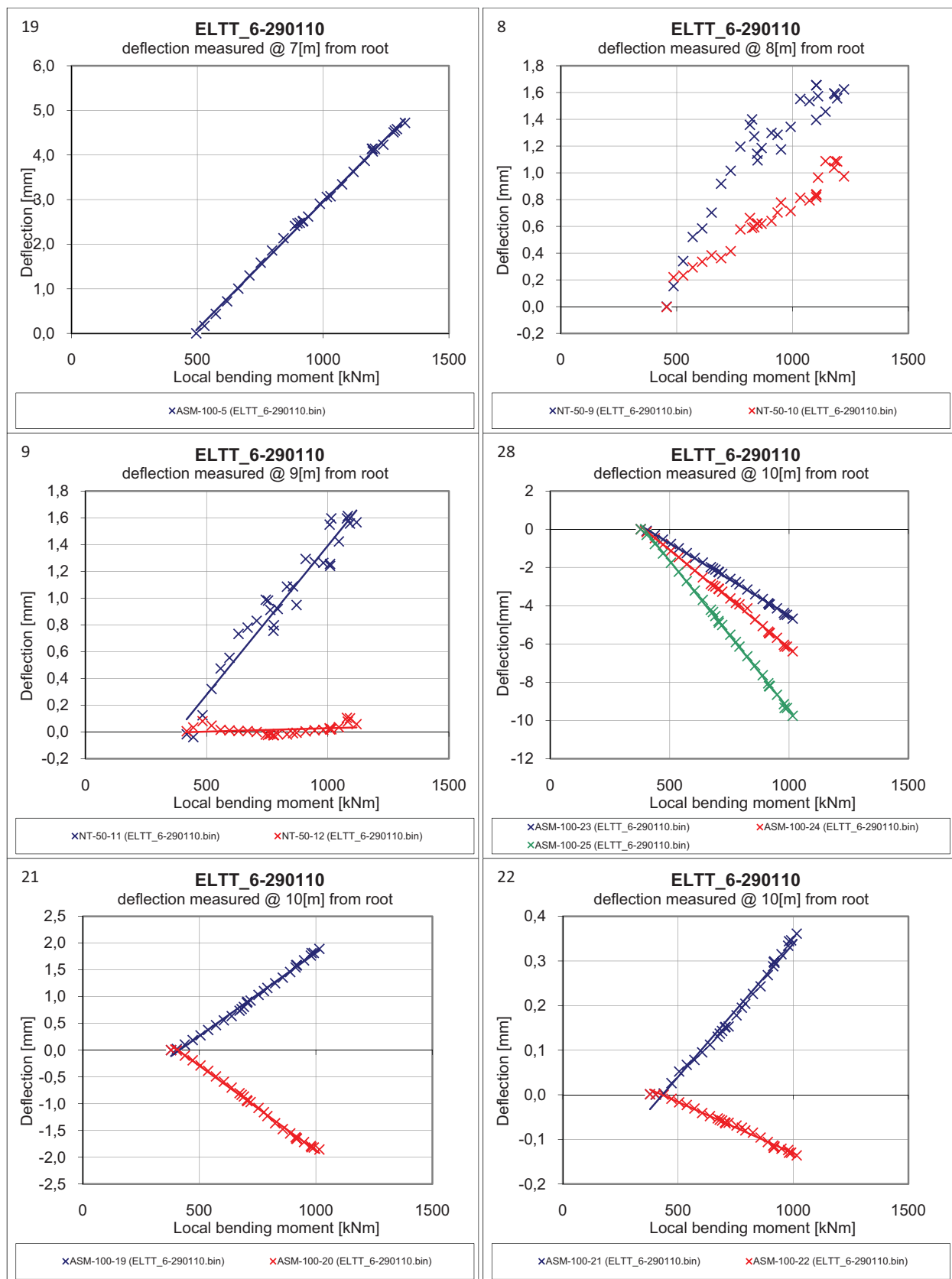
B3 Strain measurements of pull with trailing edge panel reinforcement at 80% Risø load

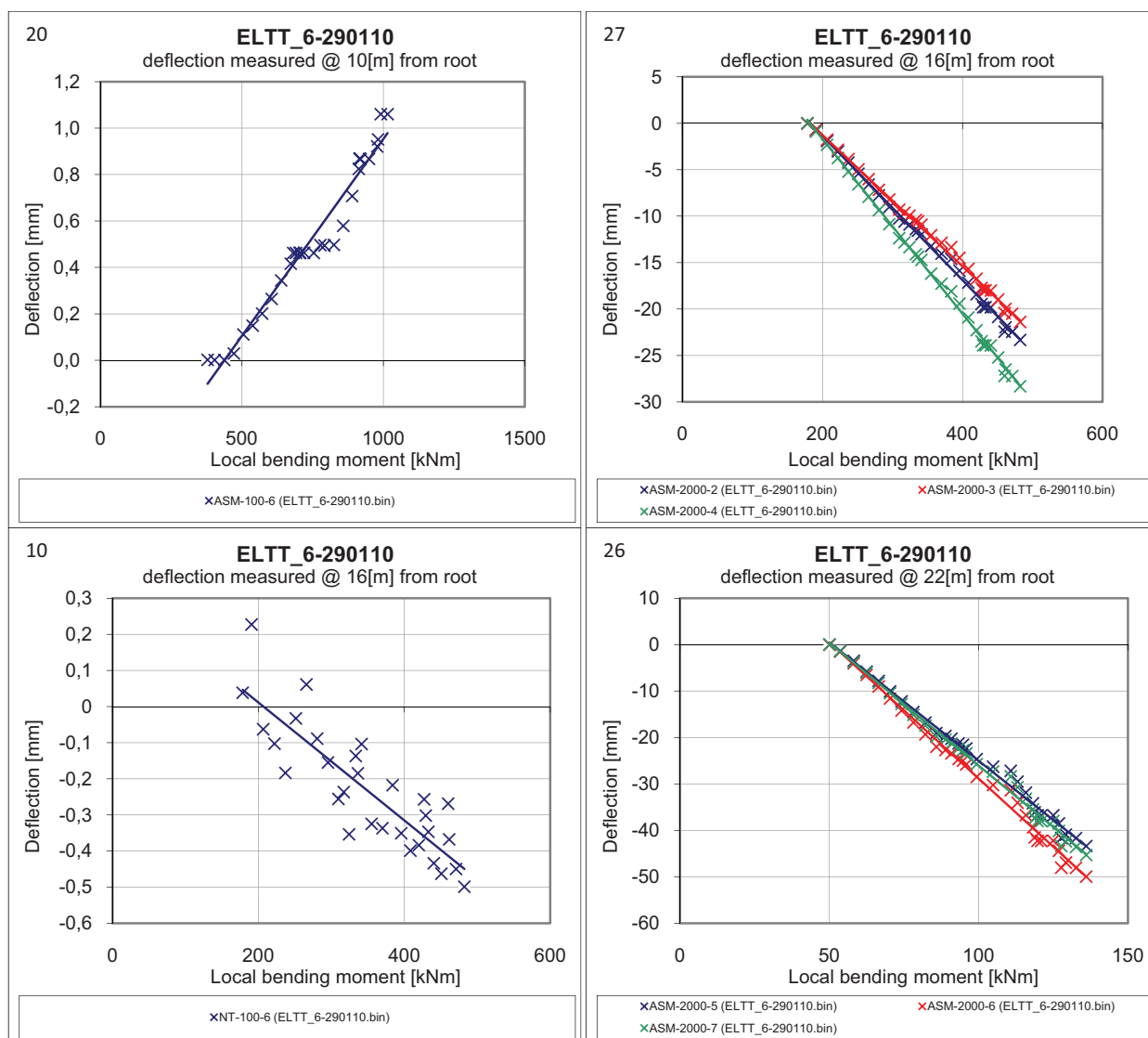
B3a ELLT_6_290110





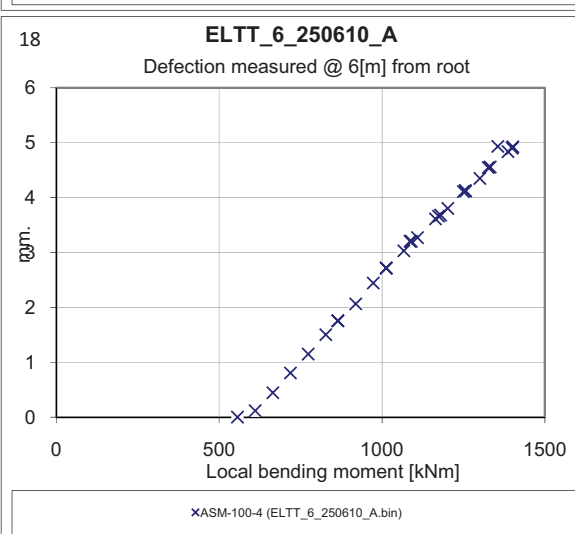
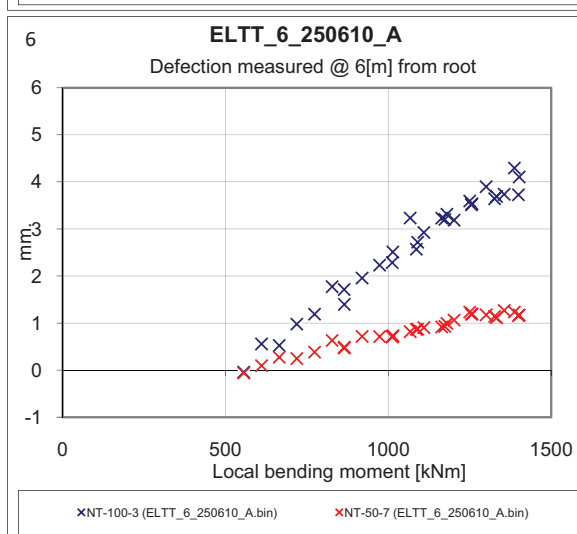
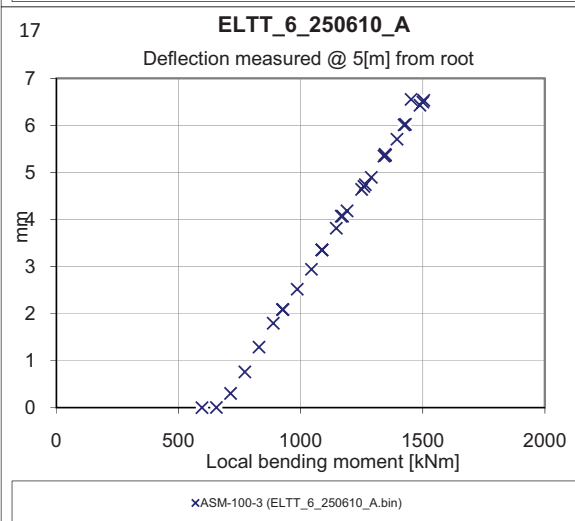
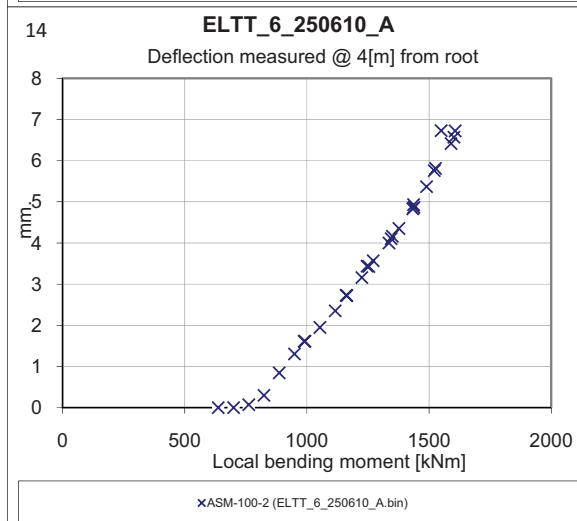
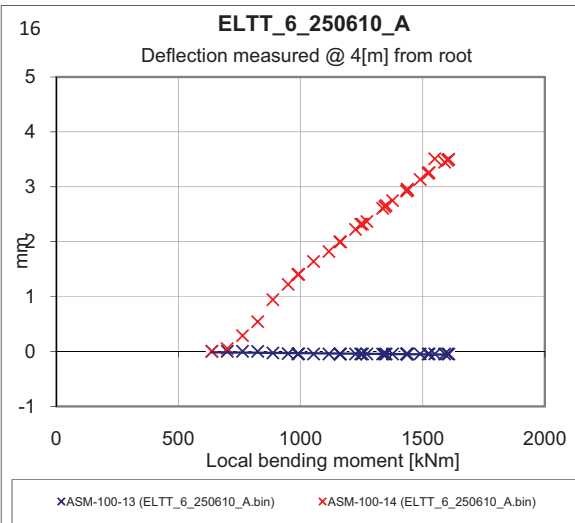
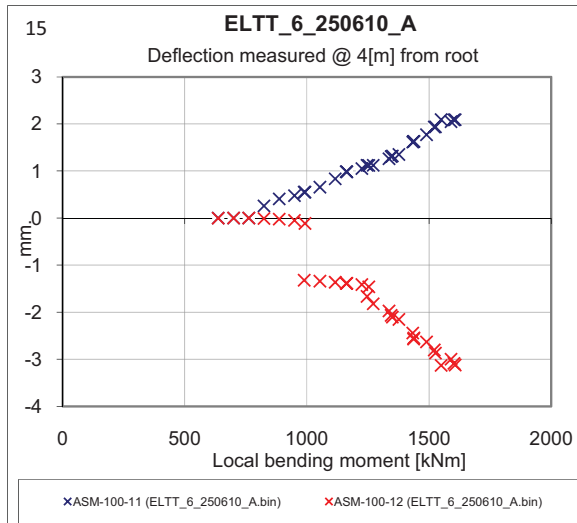


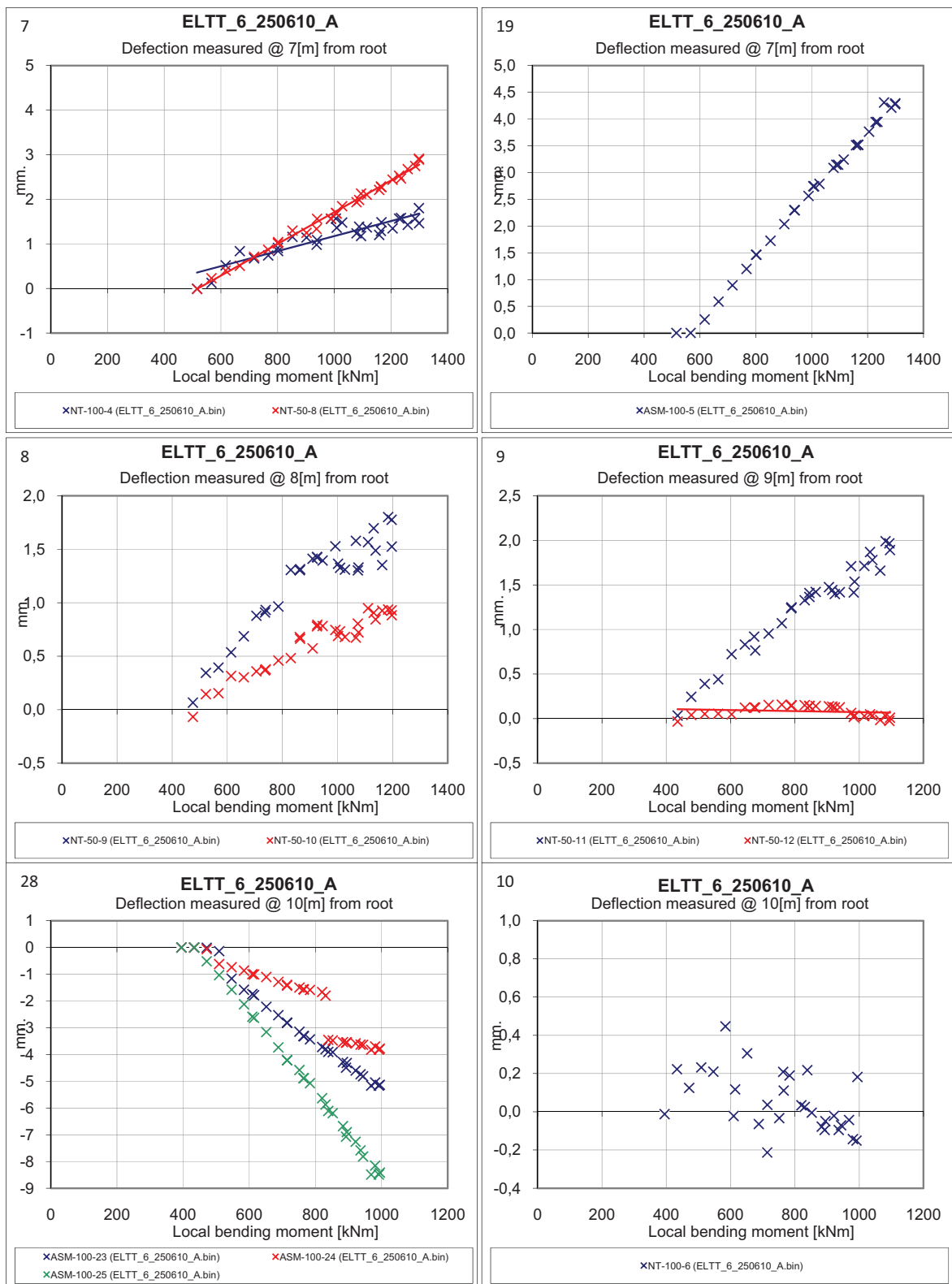


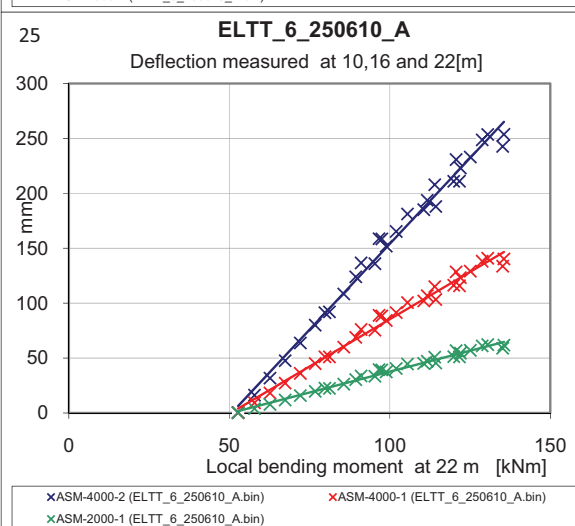
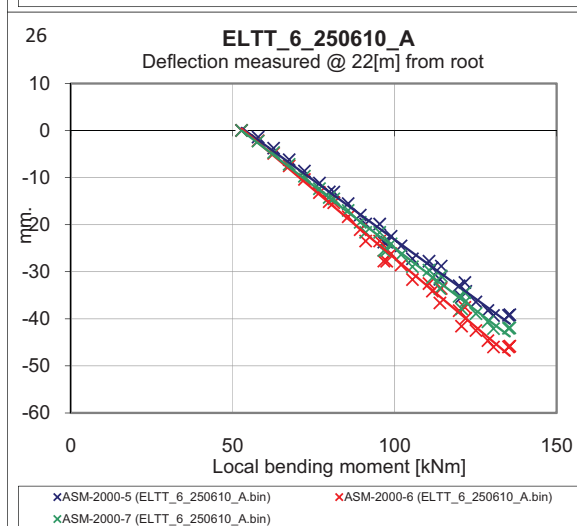
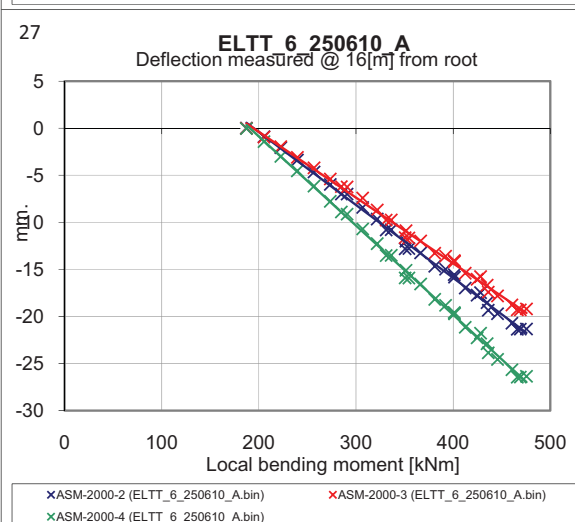
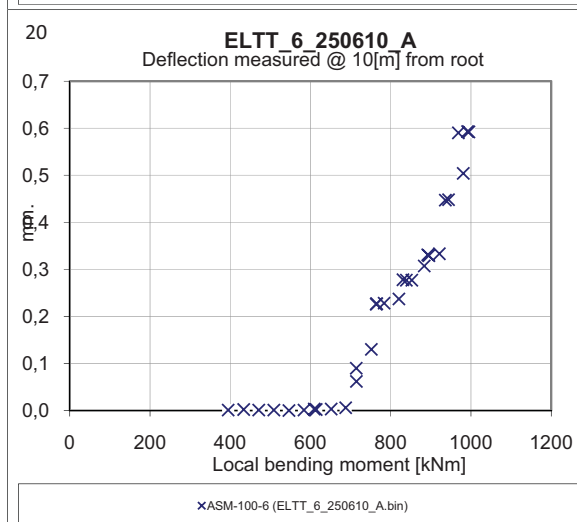
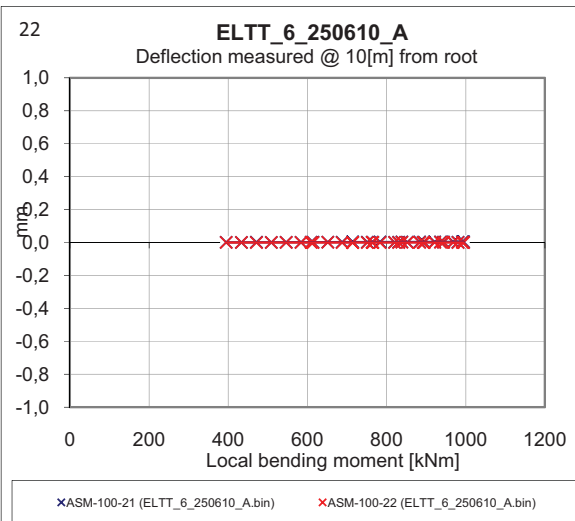
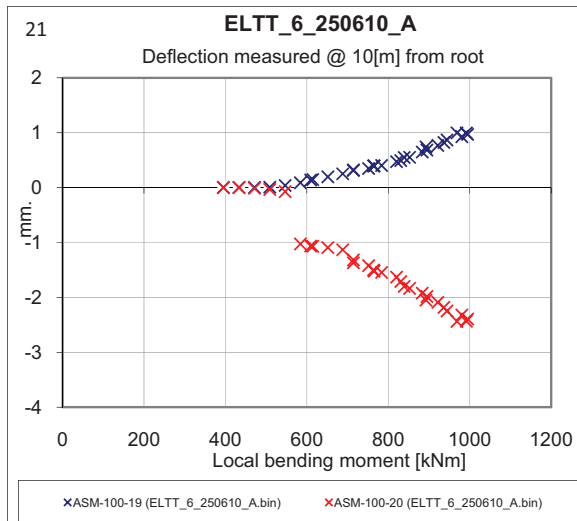


B3b

ELTT_6_250610_A

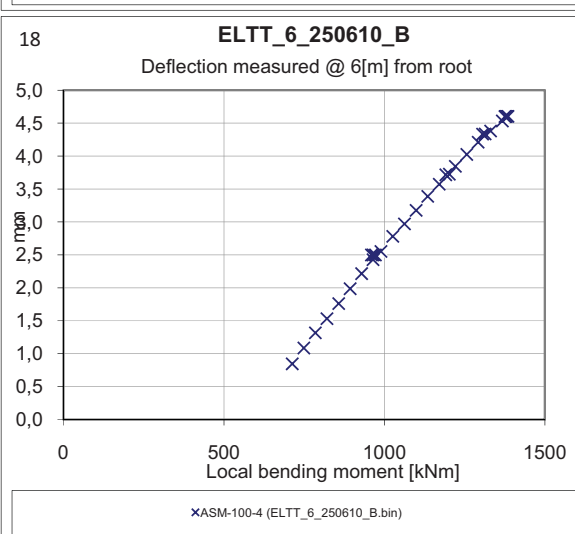
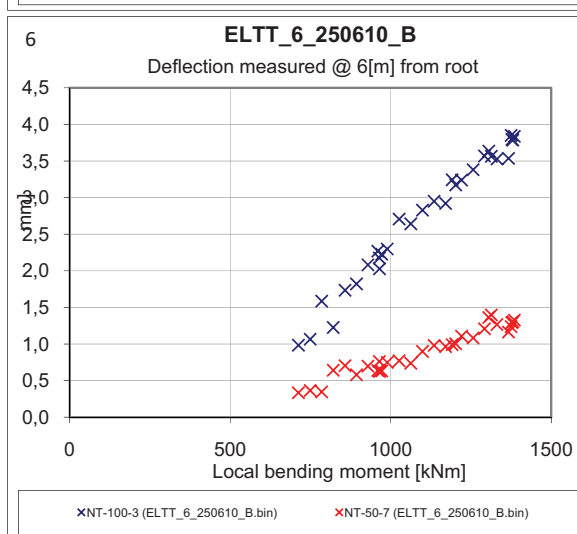
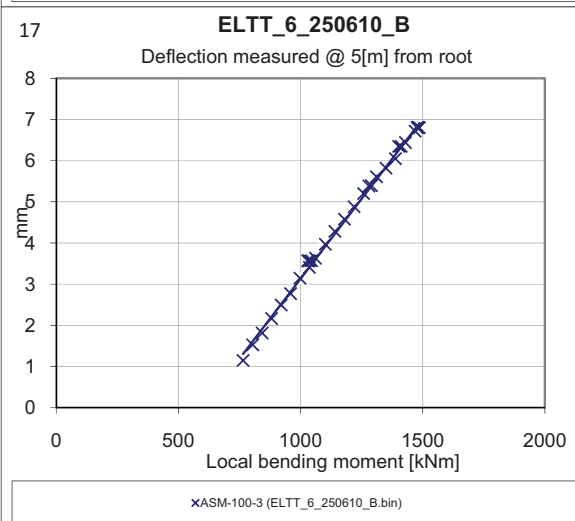
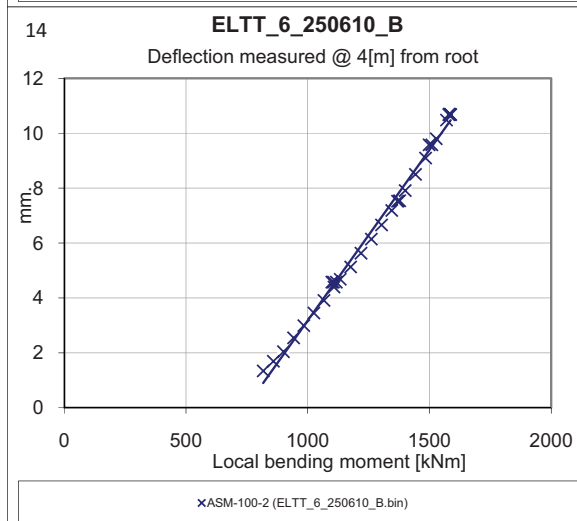
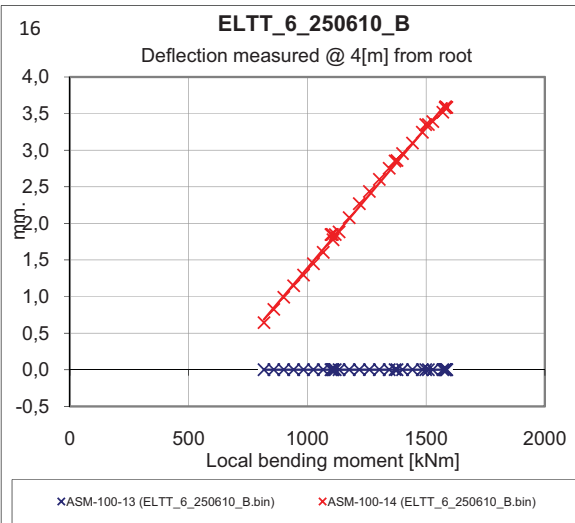
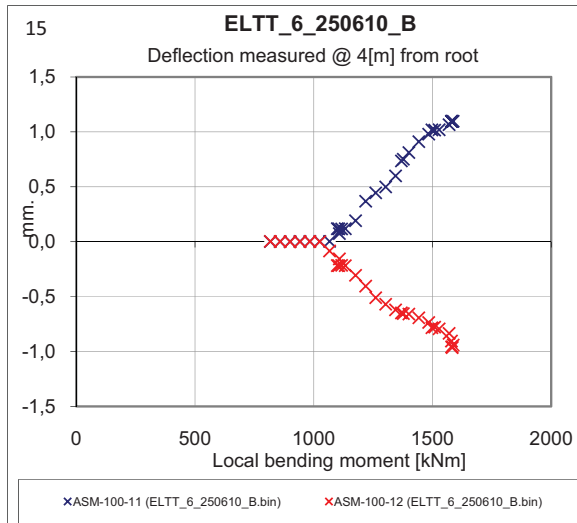


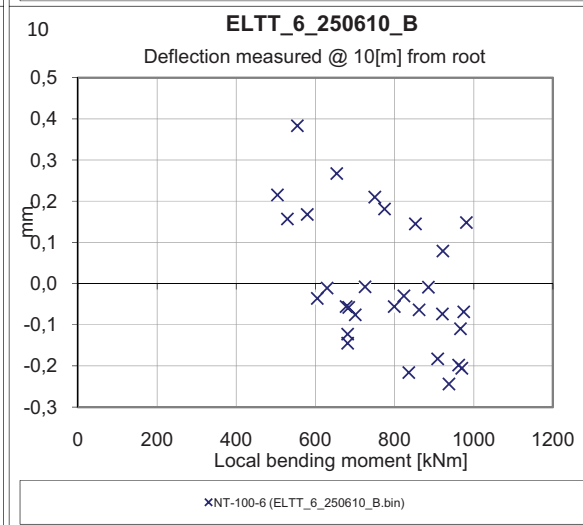
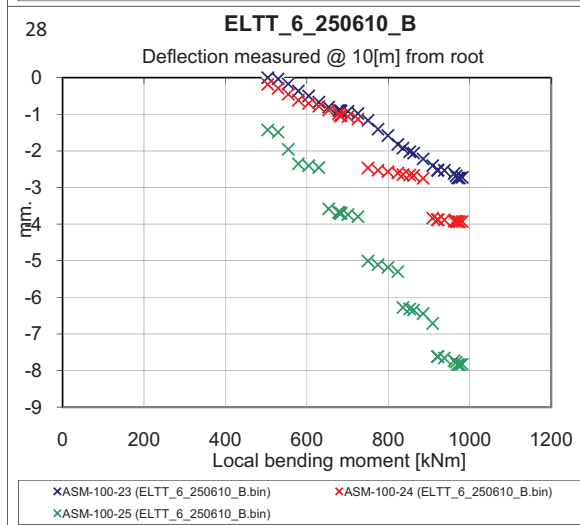
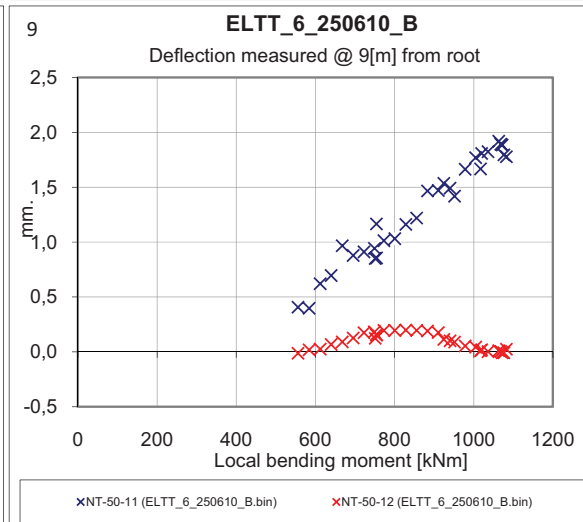
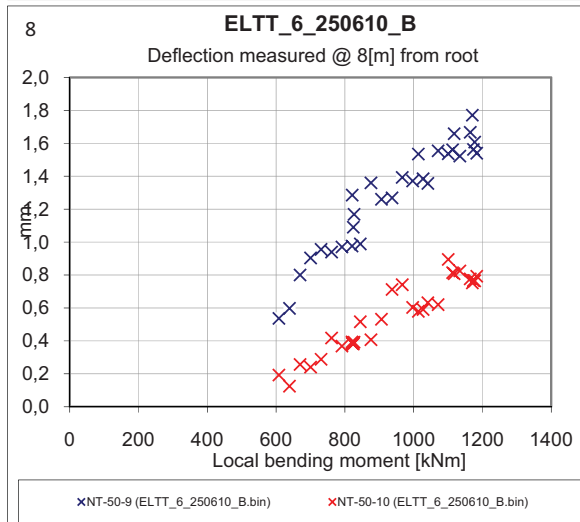
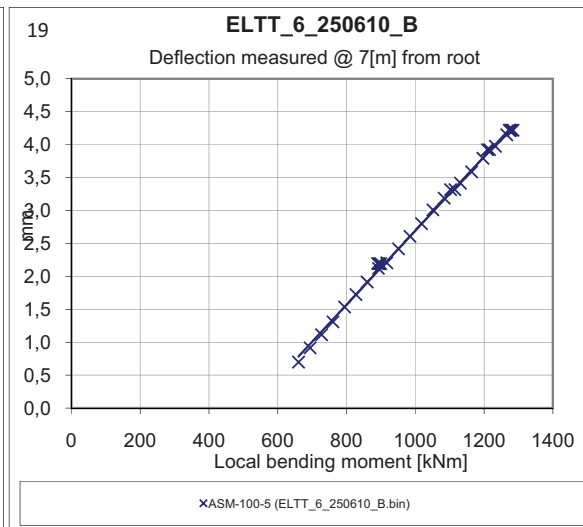
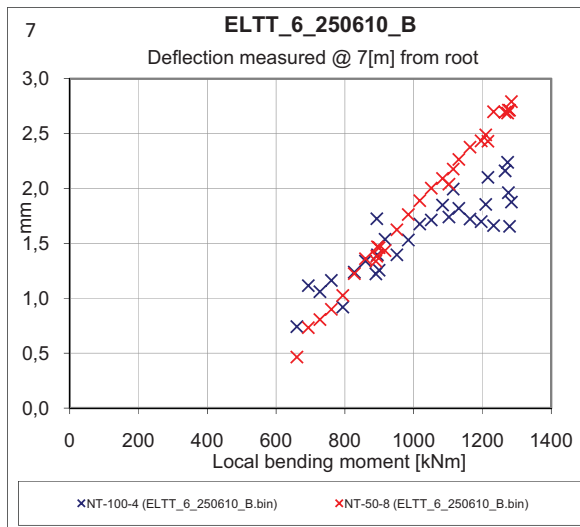


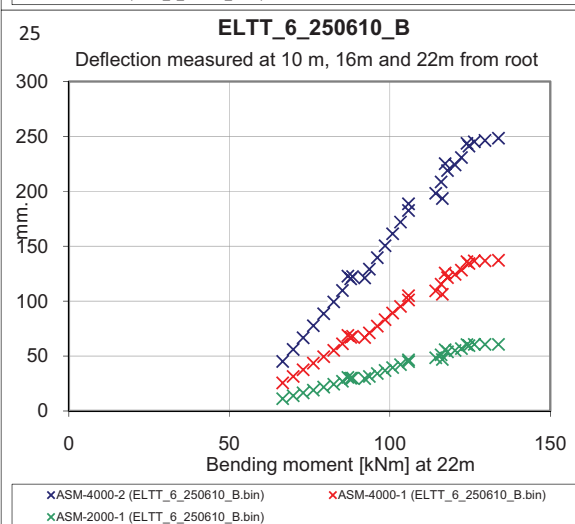
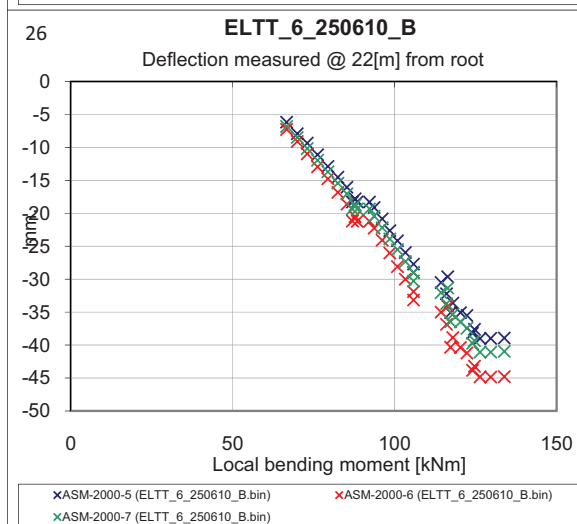
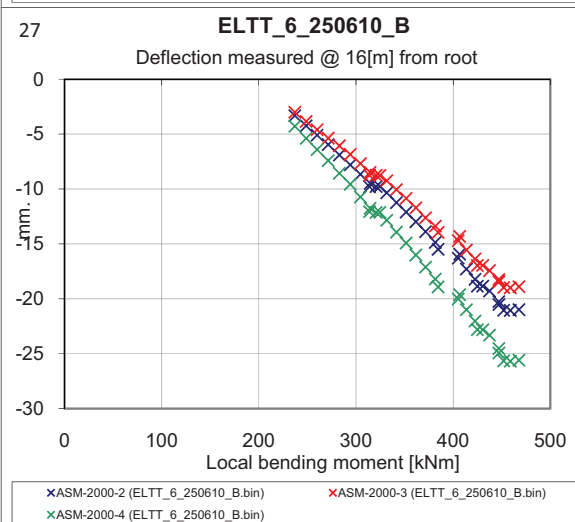
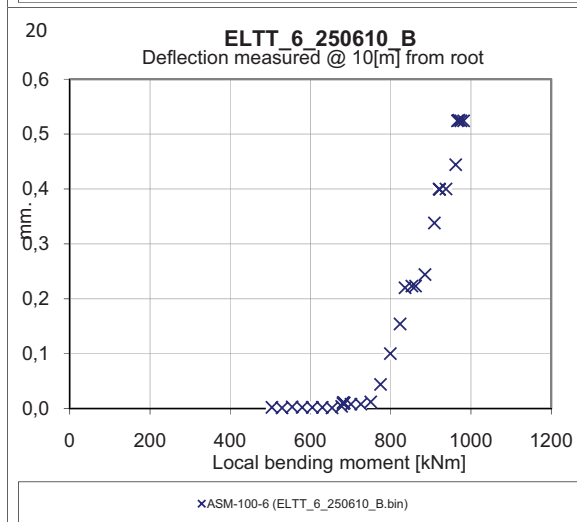
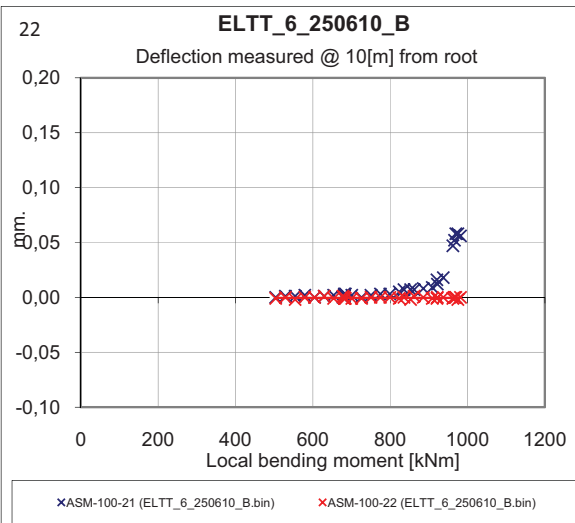
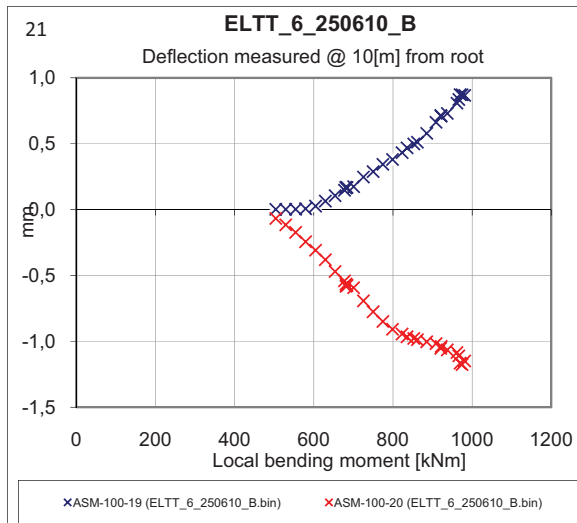


B3c

ELTT_6_250610_B

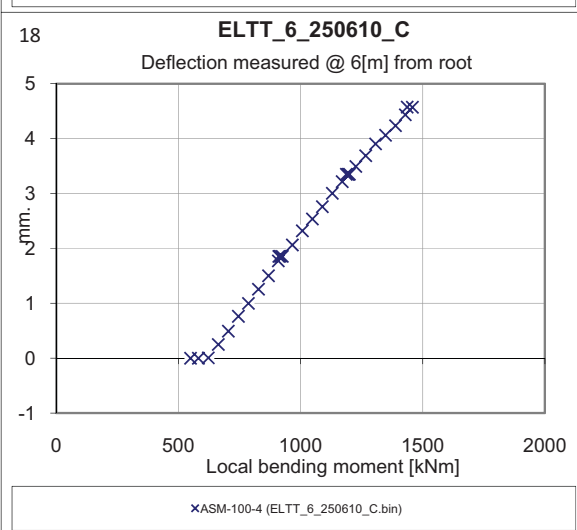
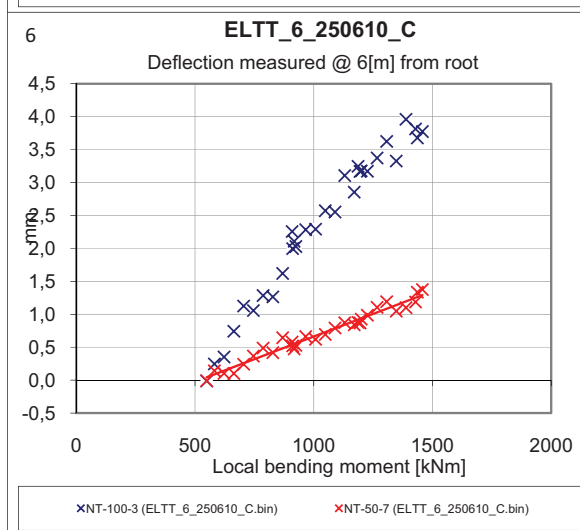
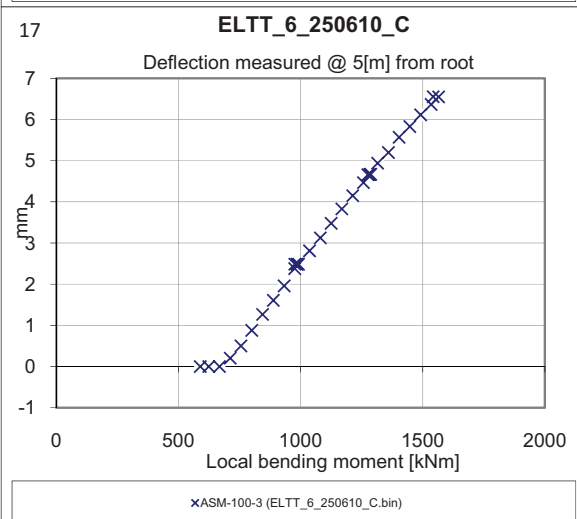
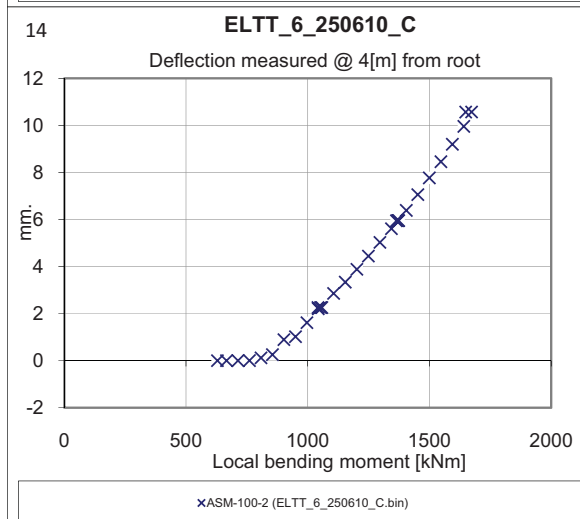
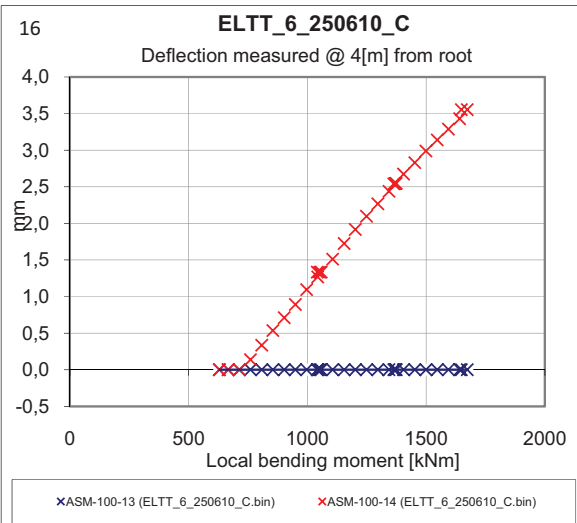
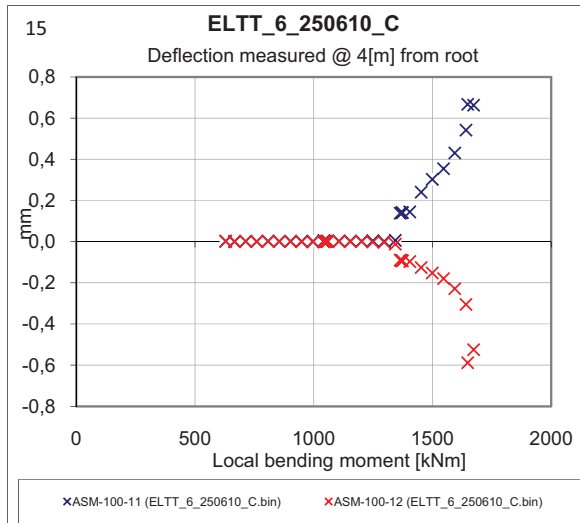


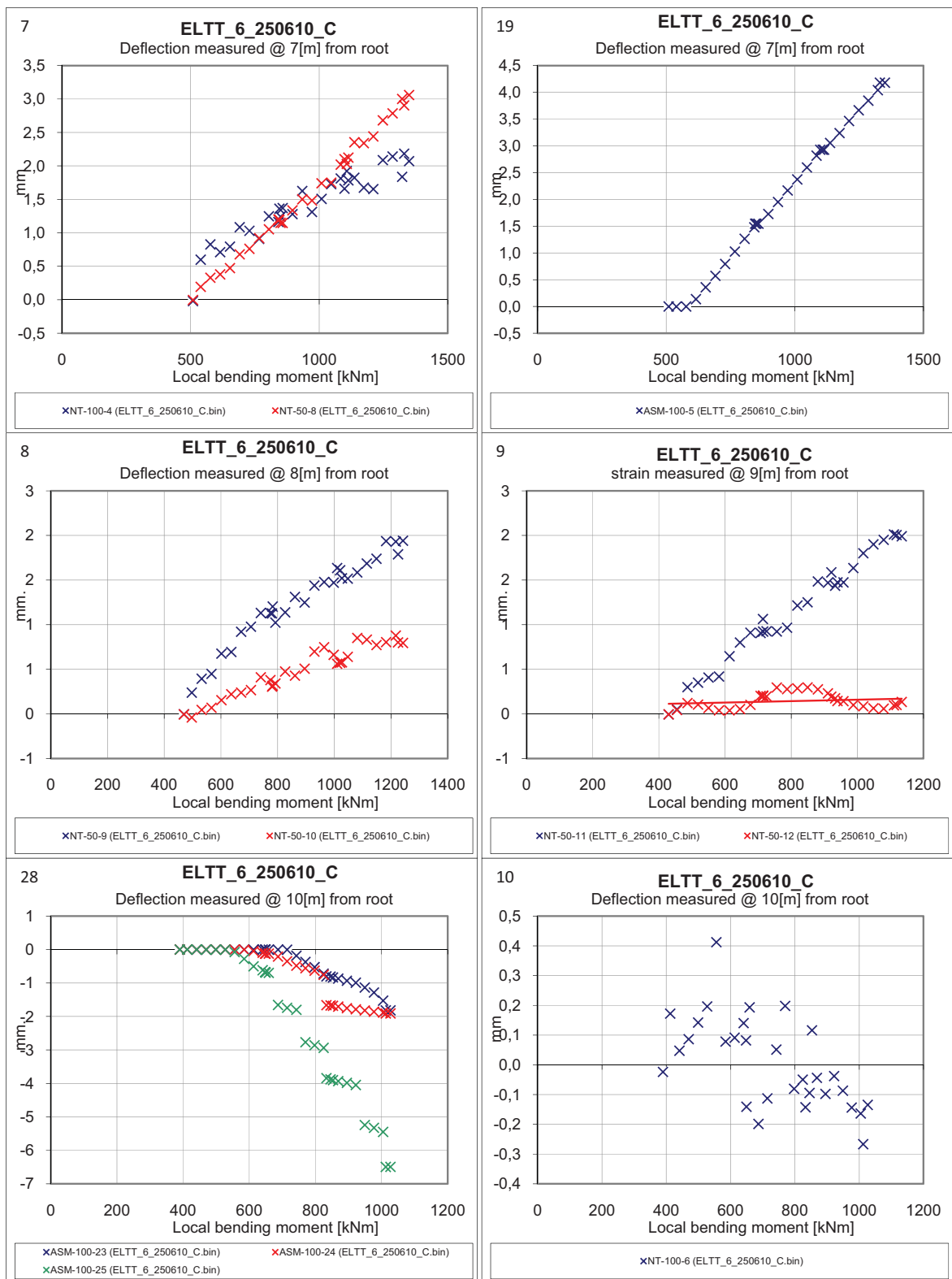


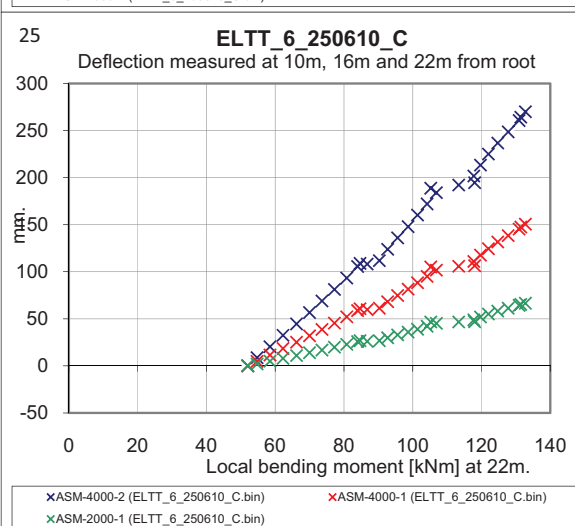
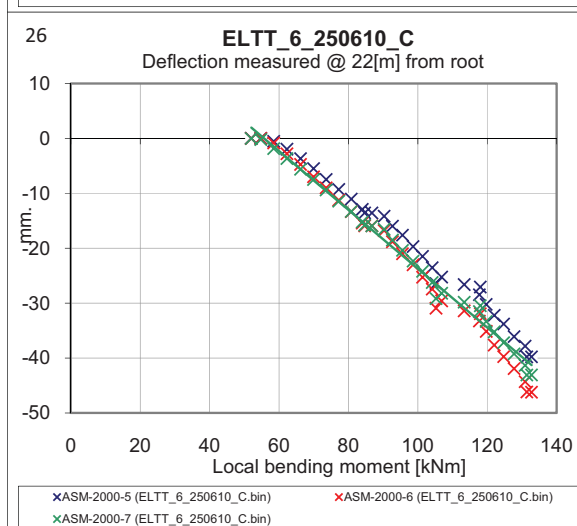
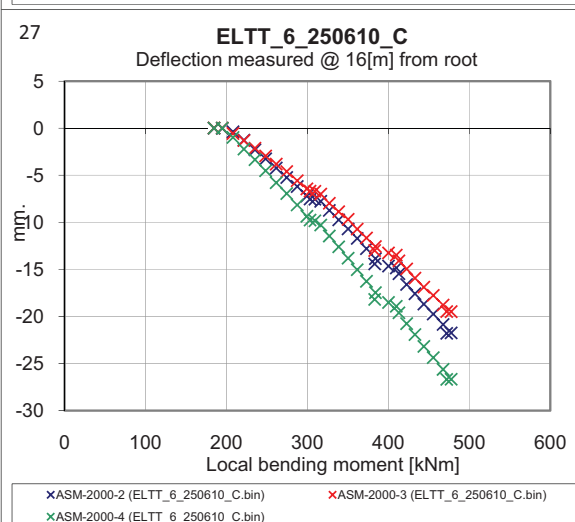
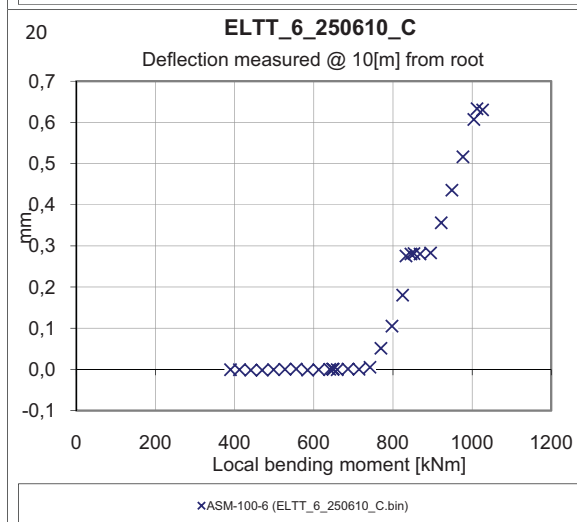
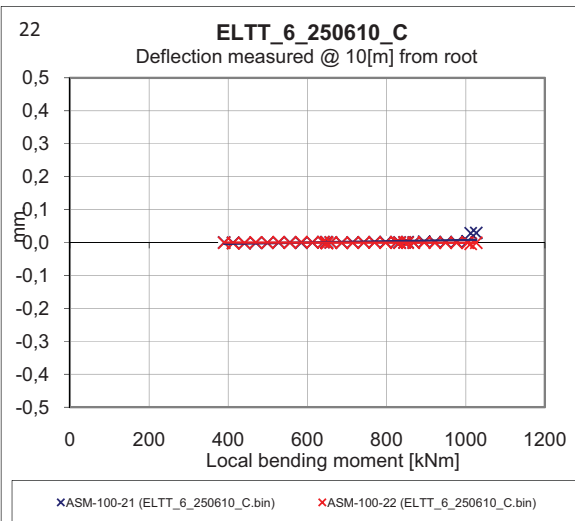
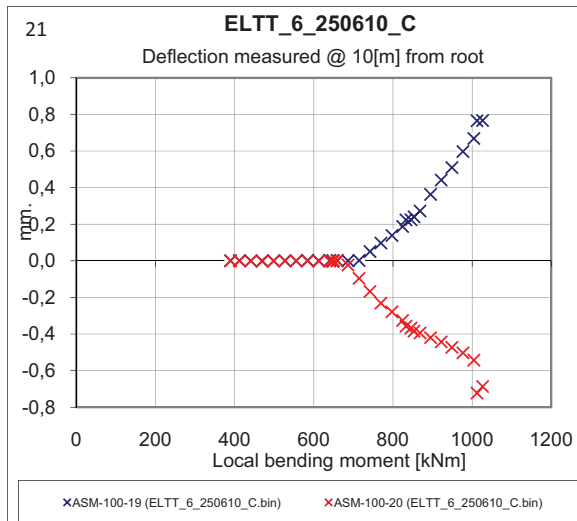


B3d

ELTT_6_250610_C







Appendix C – Acoustic Emission

Blade test at VIM facility

1615140-00 (AFM PSP for this work)

Friday 25th June 2010

Arrive early

System installed and Sensors checked by **0800**

Pocket PAC running bladetest01.lay (40dB THS, 26dB gain from inline preamp)

CH1 4m Trailing edge RED

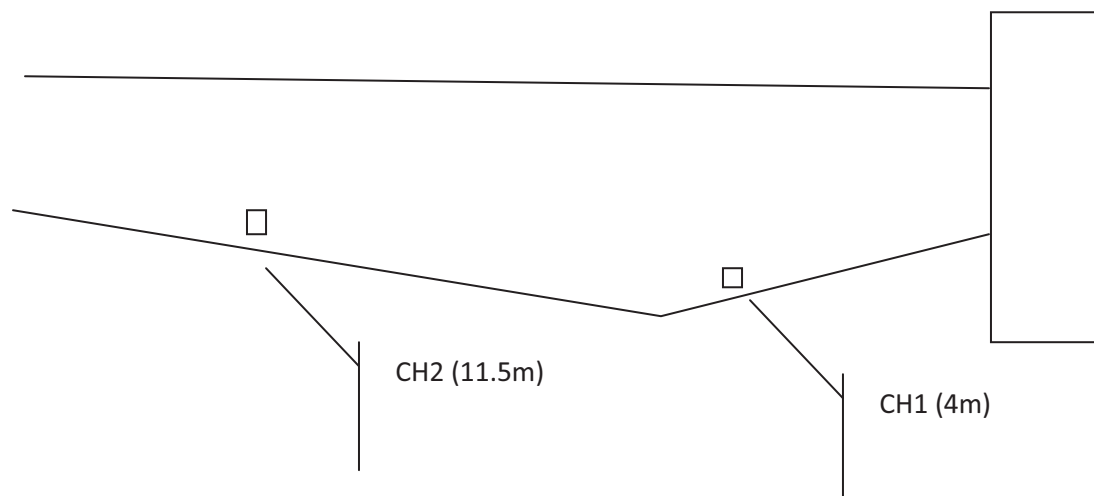
CH2 11,5m Trailing edge GREEN

Both sensors are sensitive returning hits from strip flicks 1,5m away on either face

The blade will be tested to 80% load but not broken!

11,5m is a critical area and activity here is likely to stop the test → AE monitoring key today

This loading is a repeat of the test done in January (100129), the reason for the repeat is to get the ARAMIS system working this time.



Tap test analysis

Using a plastic strip to flick the structure close to the sensors gives amplitude hits between 45 and 85 dB, one and a half meters away the response is AMP between 40dB and 50dB.

Close	20 hits	45-85dB	650 counts	1100 NRG
1,5m	11 hits	40-46db	50 counts	20 NRG

Other test set up

Delay for breakfast

Sensor check again → CH1 sensor has twisted in the tape!

Has to be re-set; but there is a risk this could occur again...

I can see from the AMP trace that about 2k seconds there was a series of hits, and a single one at 4,5k on CH1 These hits show no visibility on the count trace and very slight on the NRG. Could have been tape peel followed by sensor turn...?

1000 Ready to test

Delay for ARAMIS

1030 Time to take CH1 down and tape it again, but I still don't like...

Load to 30% Pre-load.

1045 Test start

40% no AE

60% blip at 11,5m

70% more at 11,5m and a blip at 4m

80% a few more hits at both locations

1050 The load is kept

1115 Drive down to 30%

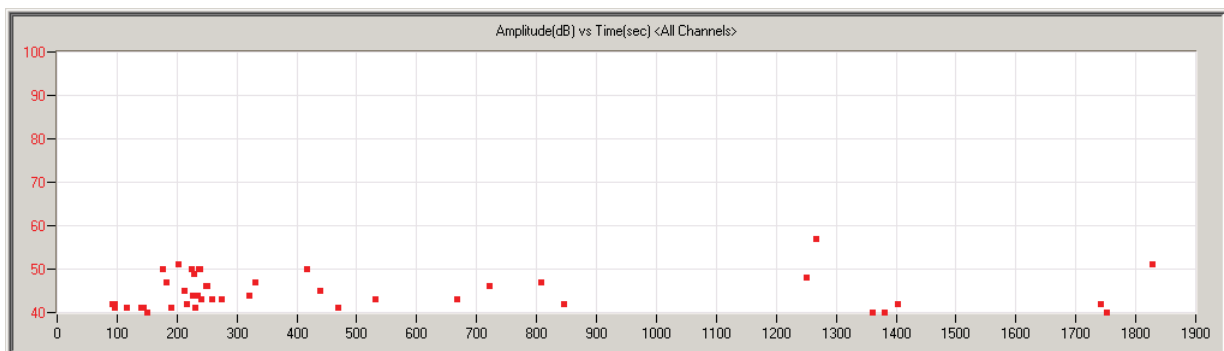
1125 Now everyone is in and looking at the blade.

1130 Drive down to almost 0 load on all cells

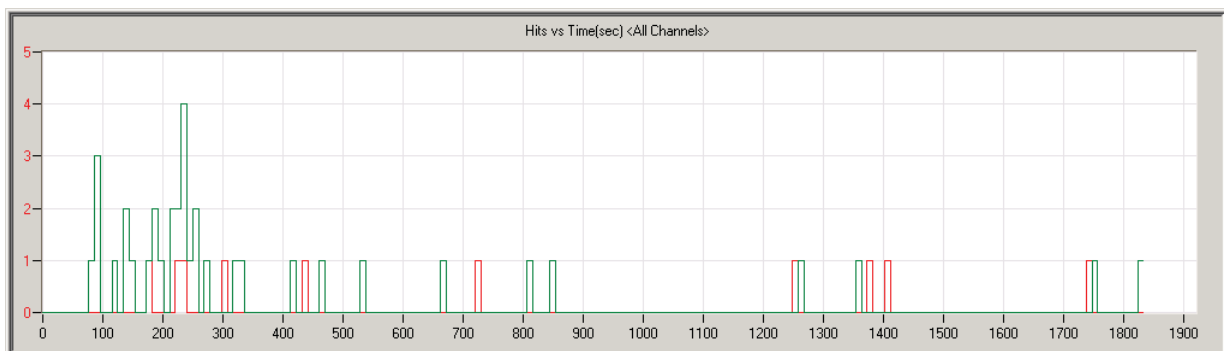
Test finished.

GRAPHS (extracted from DiSP system bladeviewer.lay)

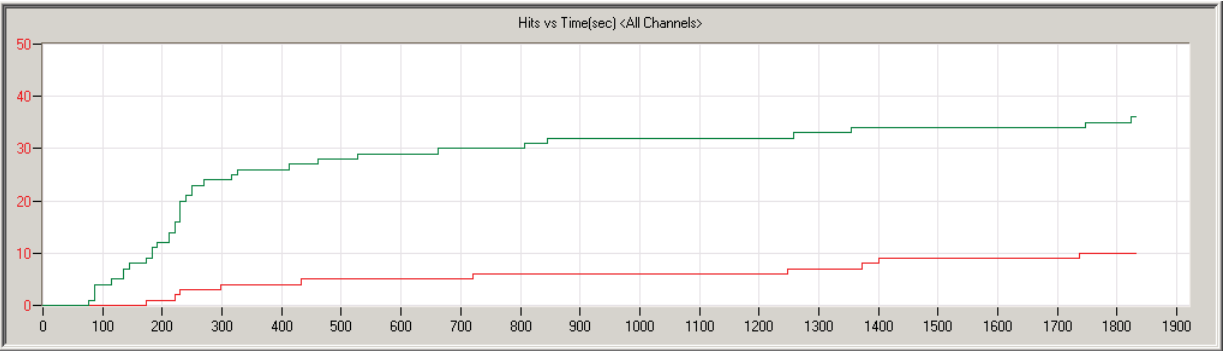
AMP vs time (point) All hits from Ch1 and 2



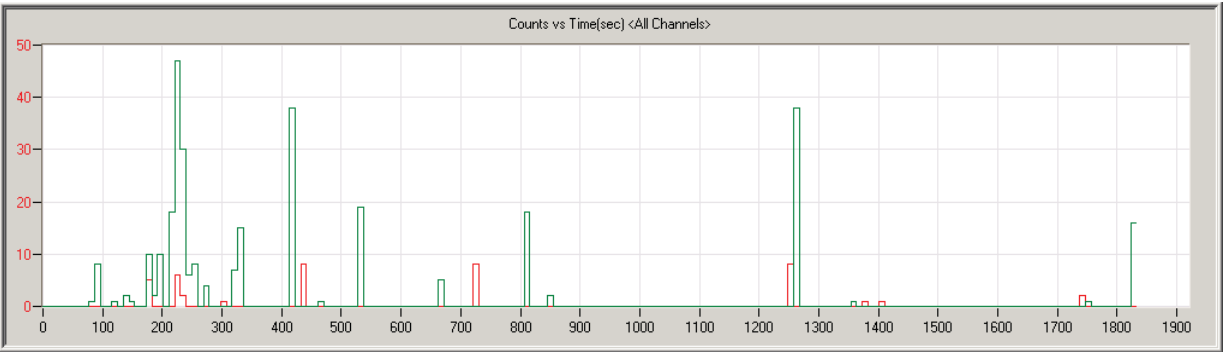
Hits vs time (Burst) Ch1/4m – RED, Ch2/11m - GREEN



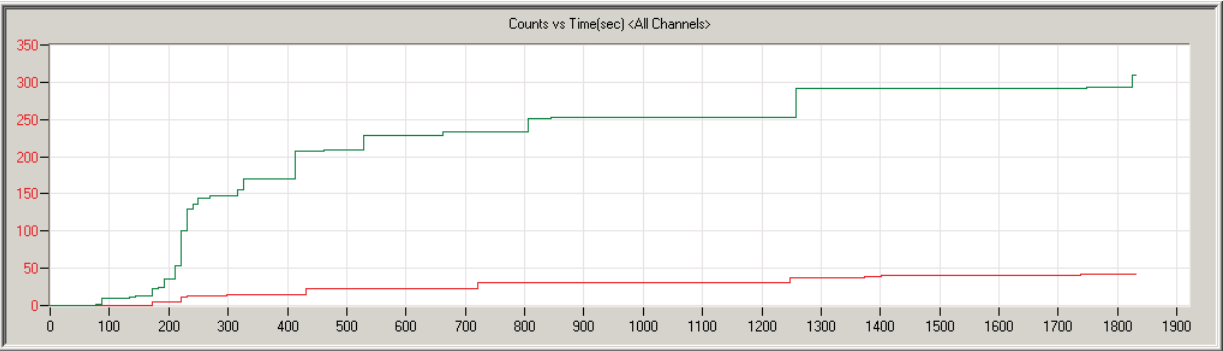
Hits vs time (CUM) Ch1/4m – RED, Ch2/11m - GREEN



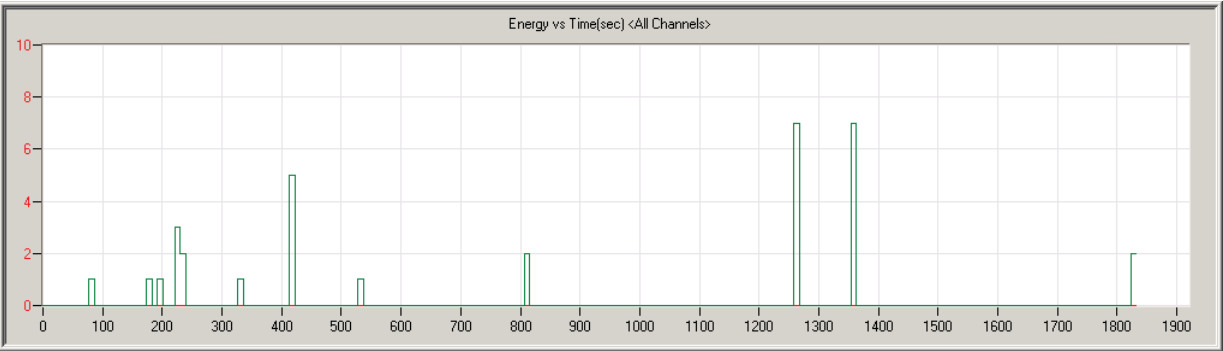
Cnts vs time (Burst) Ch1/4m – RED, Ch2/11m - GREEN



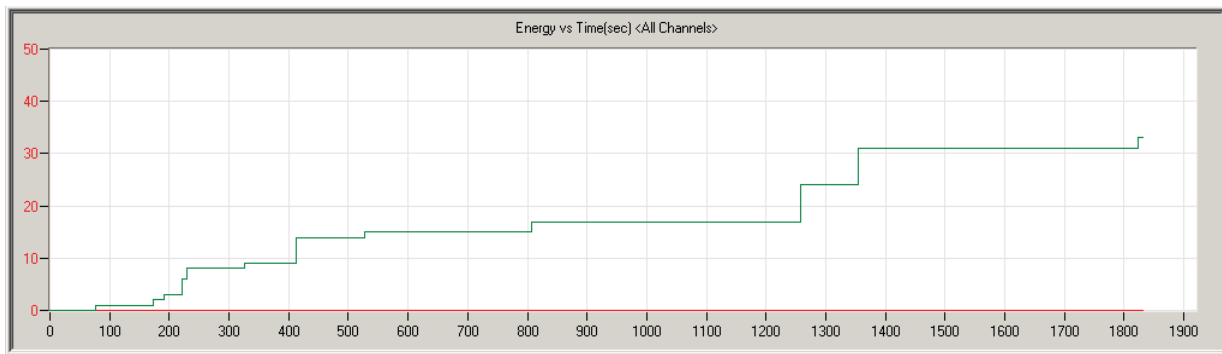
Cnts vs time (CUM) Ch1/4m – RED, Ch2/11m - GREEN



Energy vs time (Burst) Ch1/4m – RED, Ch2/11m - GREEN



Energy vs time (CUM) Ch1/4m – RED, Ch2/11m - GREEN



Thursday 28th pm

System installed and Sensors checked

Pocket PAC running bladetest01.lay (40dB THS, 26dB gain from inline preamp)

Friday 29th

0800 Sensors attached – CH1 at 4m trailing edge, CH2 at 11,5m trailing edge

The blade will be tested to 80% load but not broken!

11,5m is a critical area and activity here is likely to stop the test → AE monitoring key today

The sensors are sensitive returning high AMP hits from lead breaks up to 1m away on either face.

0900 Breakfast at VEA while they try to get ARAMIS to work...

1030 Back to do the test with or without ARAMIS

1050 Test starts at 30% load

Direct load up to 81% and down again

Data stopped at 1100

First hits at 11,5m after 30s

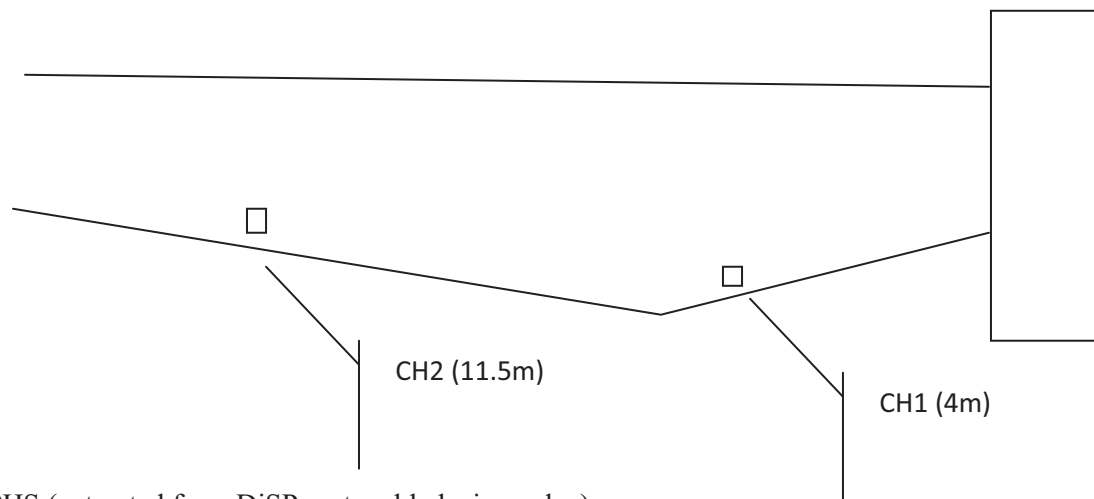
First hits at 4m after 150s

All hits detected were low energy and under 60dB

EXCEPT for one hit of 65dB at 11,5m and 81% load

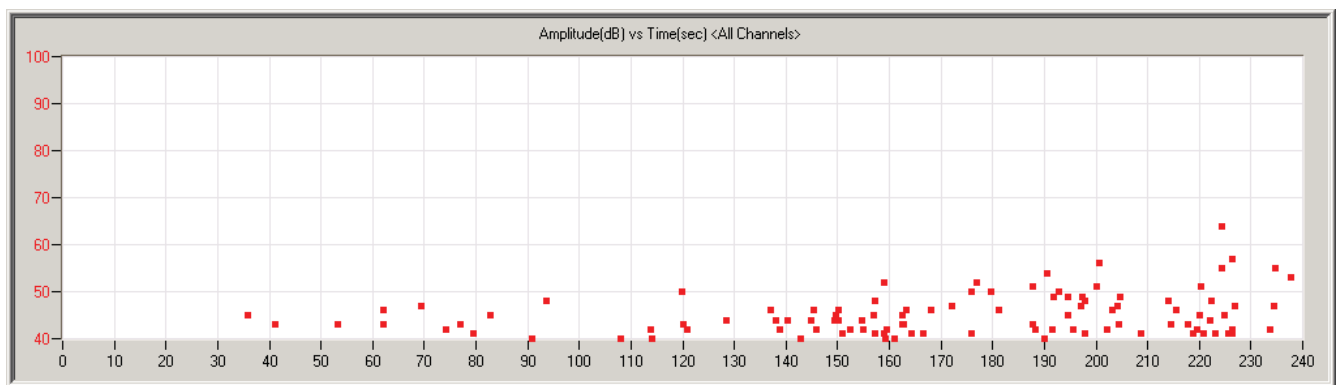
Total activity CH1 (4m) 100 Counts

Total activity CH2 (11,5m) 700 Counts

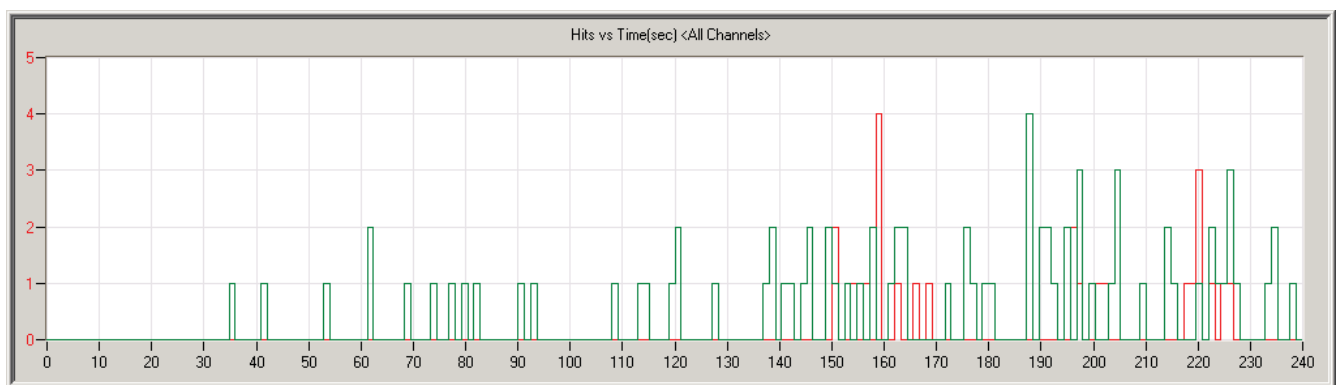


GRAPHs (extracted from DiSP system bladeviewer.lay)

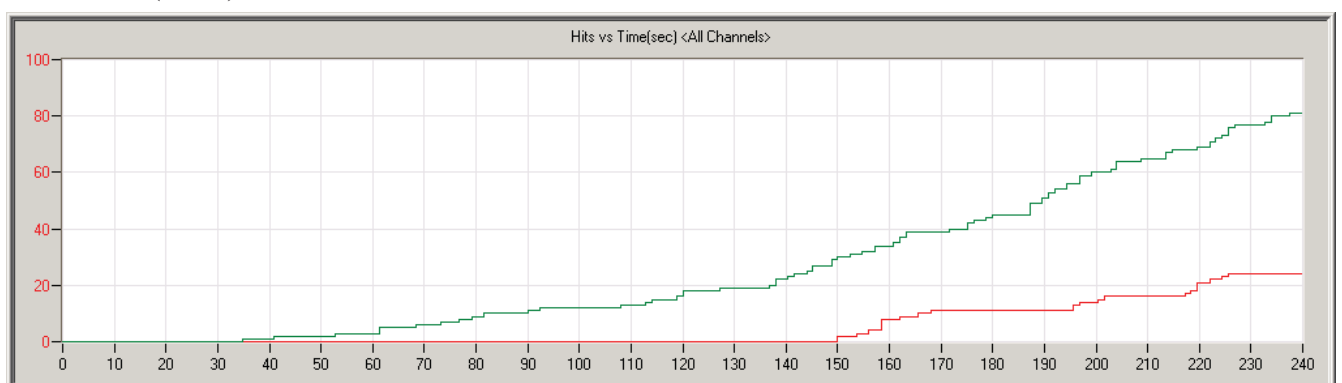
AMP vs time (point) All hits from Ch1 and 2



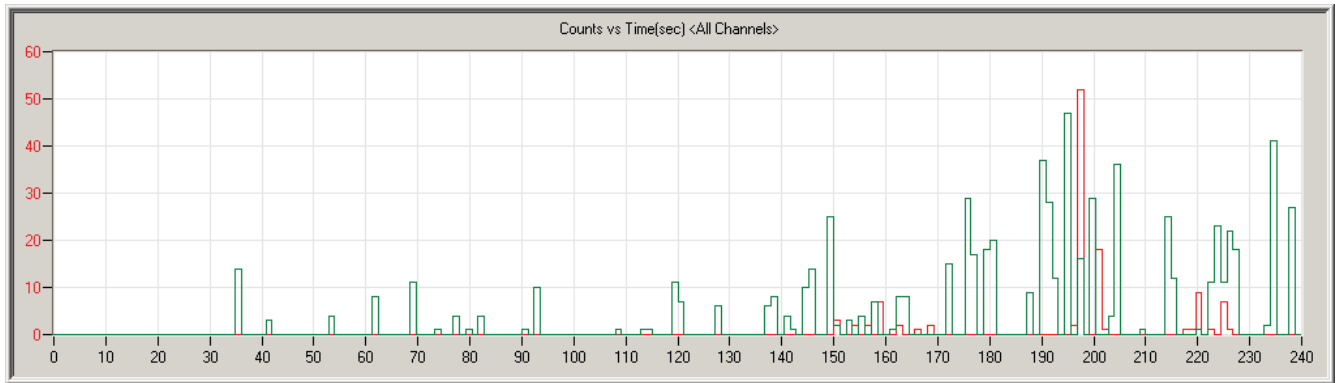
Hits vs time (Burst) Ch1/4m – RED, Ch2/11m - GREEN



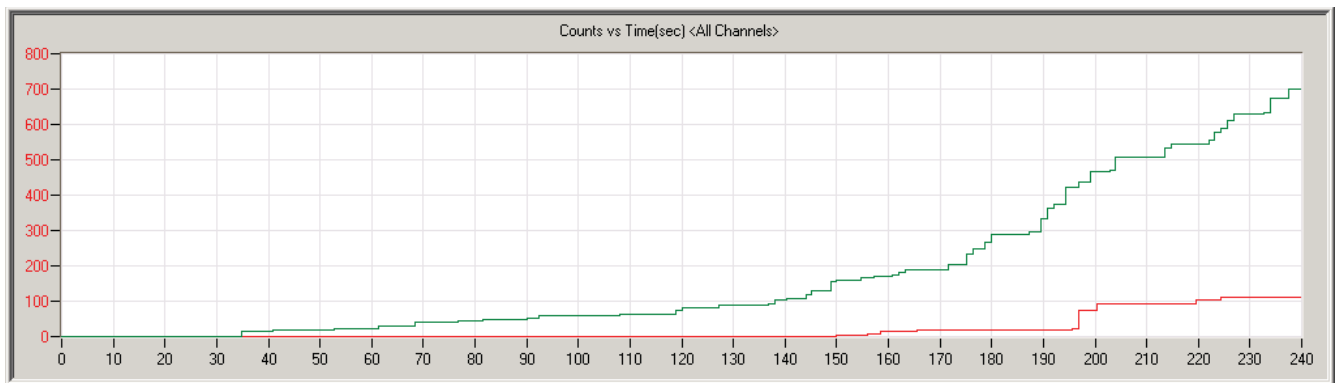
Hits vs time (CUM) Ch1/4m – RED, Ch2/11m - GREEN



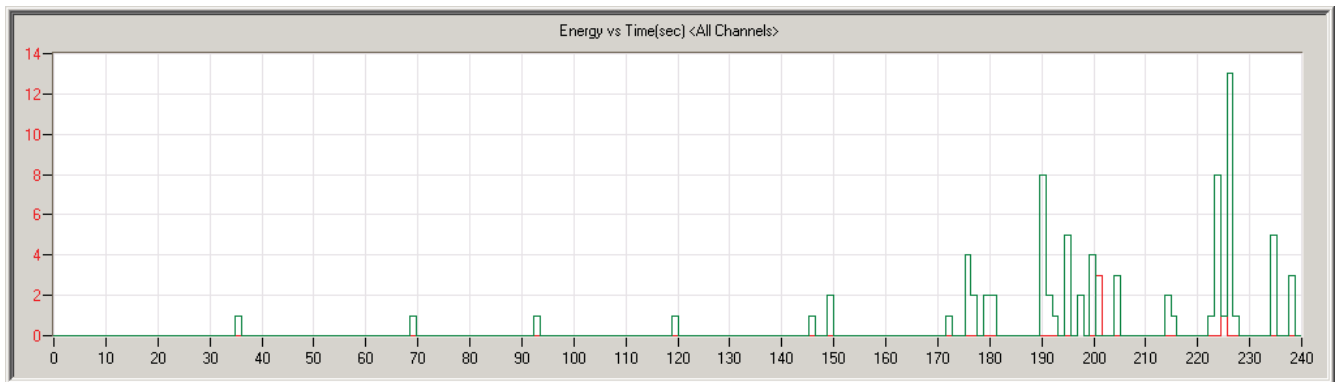
Cnts vs time (Burst) Ch1/4m – RED, Ch2/11m - GREEN



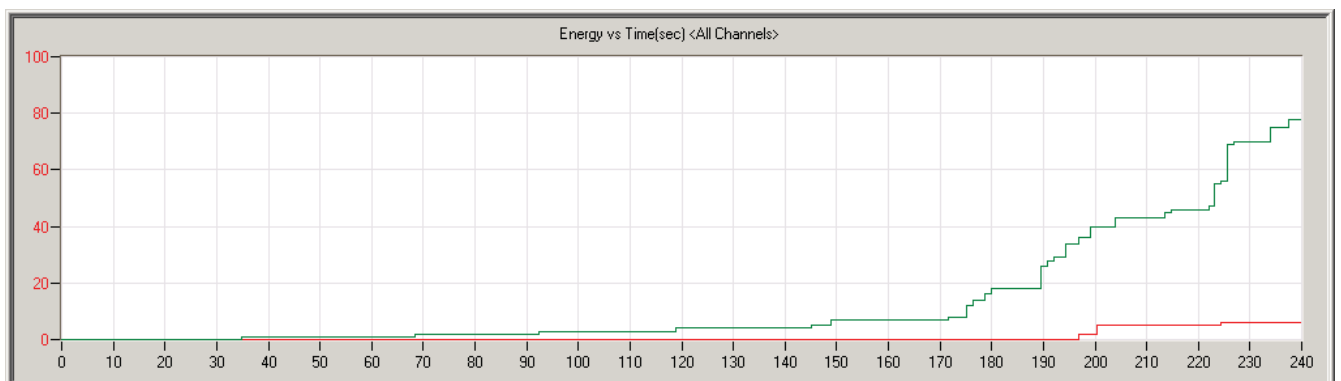
Cnts vs time (CUM) Ch1/4m – RED, Ch2/11m - GREEN



Energy vs time (Burst) Ch1/4m – RED, Ch2/11m - GREEN



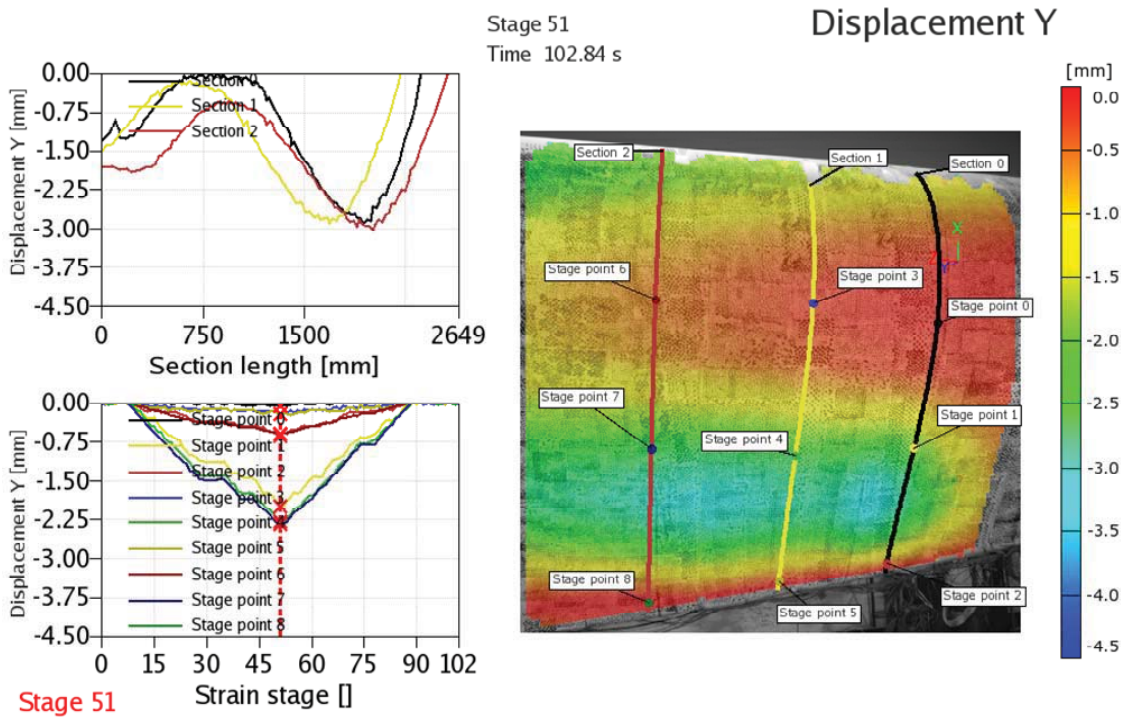
Energy vs time (CUM) Ch1/4m – RED, Ch2/11m - GREEN



Test: ELTT_5_251109_B

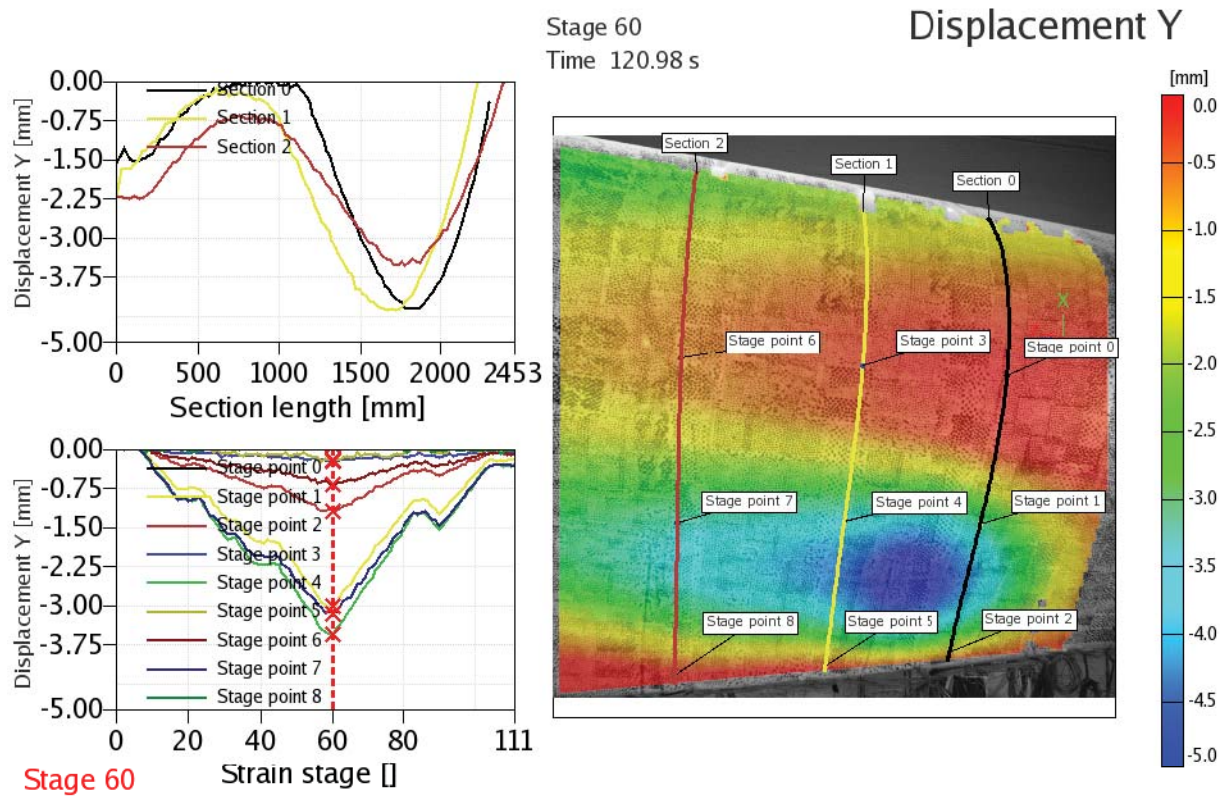
The maximum load during this test was 60%.

The DIC - measurement was conducted in the 4 meter region on the pressure side.
The blade has been reinforced, see snapshot.



Test: ELTT_2_101109_A

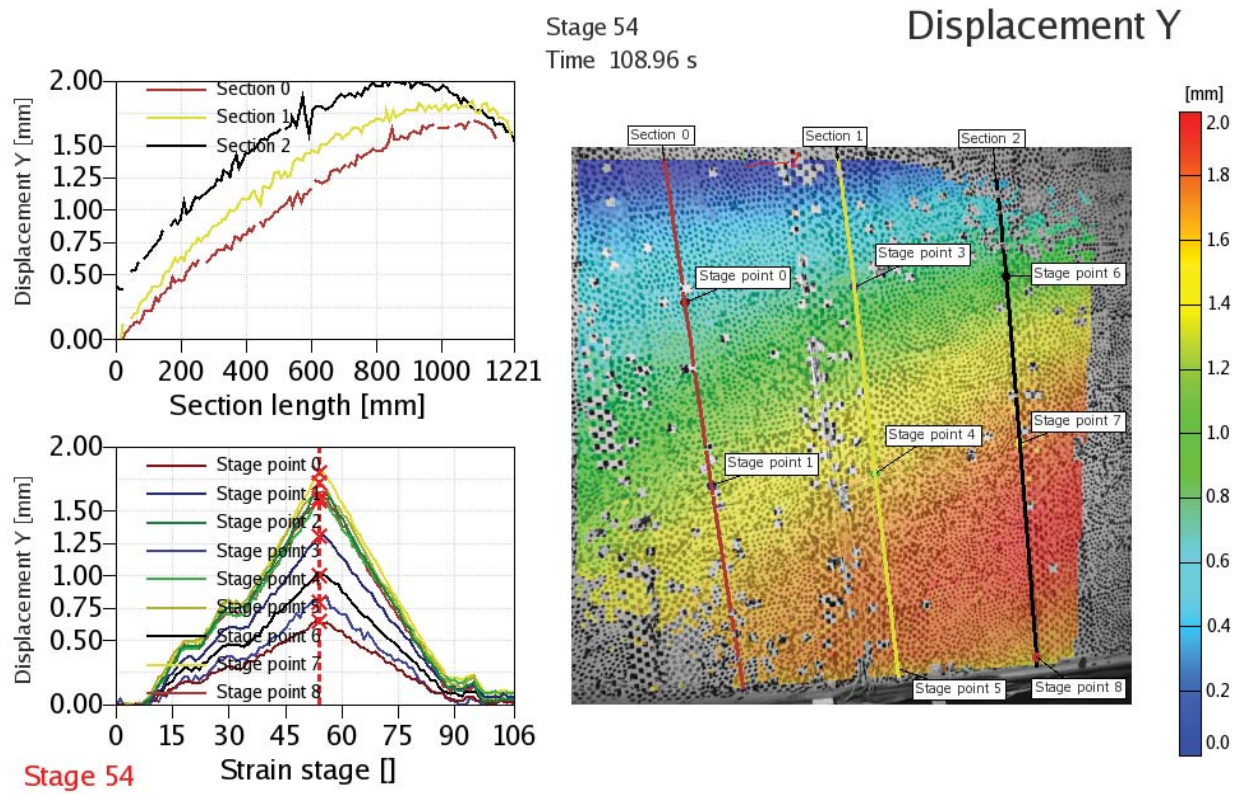
The measurement was started at 30% load.
The maximum load during this test was 60%.
The DIC - measurement was conducted in the 4 meter region on the pressure side of the blade (no reinforcement), see snapshot below.



Test: ELTT_5_181109_A

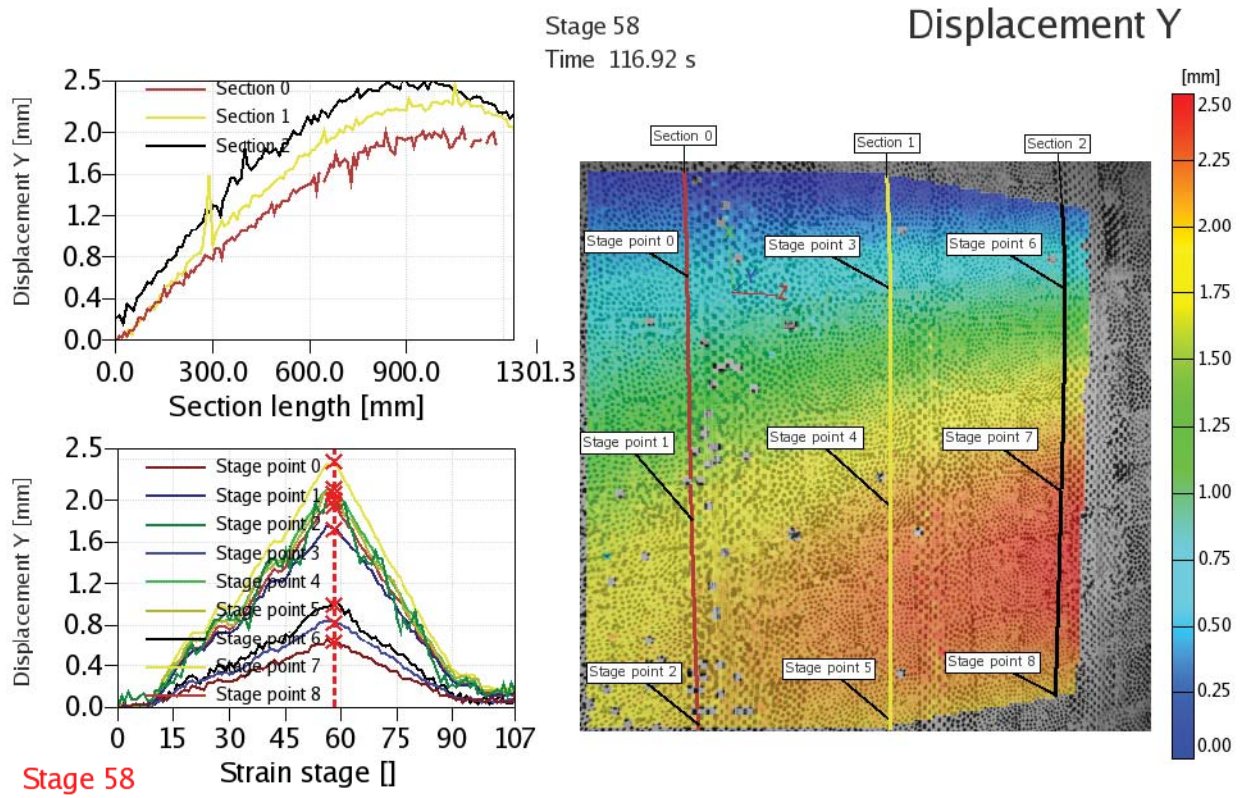
The maximum load during this test was 60%.

The DIC - measurement was conducted in the 4 meter region on the suction side where the blade was reinforced, see snapshot below.



Test: ELTT_2_171109_A

The measurement was started at 30% load.
The maximum load during this test was 60%.
The DIC - measurement was conducted in the 4 meter region on the suction side (without reinforcement) of the blade, see snapshot below.

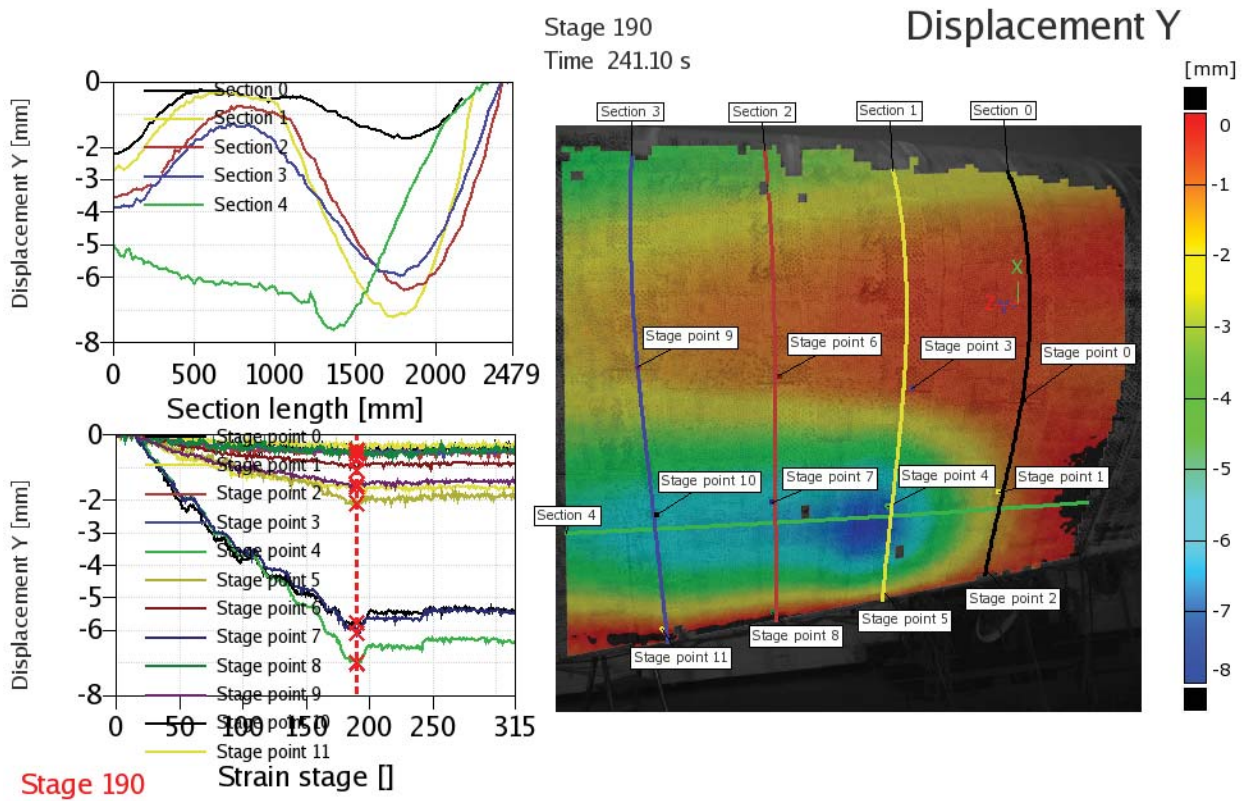


Test: ELTT_6_250610_A

The maximum load during this test was 80%.

The DIC - measurement was conducted in the 4 meter region on the pressure side.

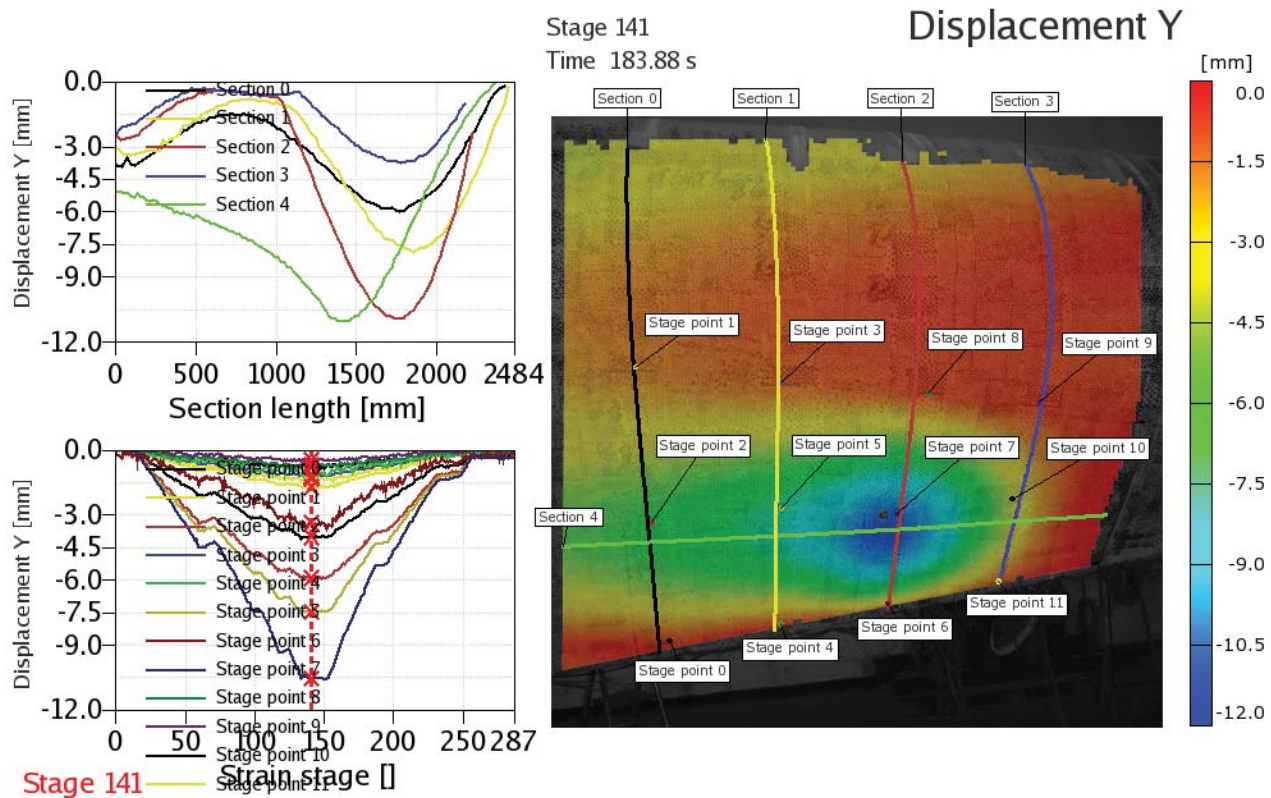
The blade has been reinforced, see snapshot.



Test: ELTT_6_250610_B

The maximum load during this test was 80%.

The DIC - measurement was conducted in the 4 meter region on the pressure side,
The blade was not reinforced, see snapshot below.

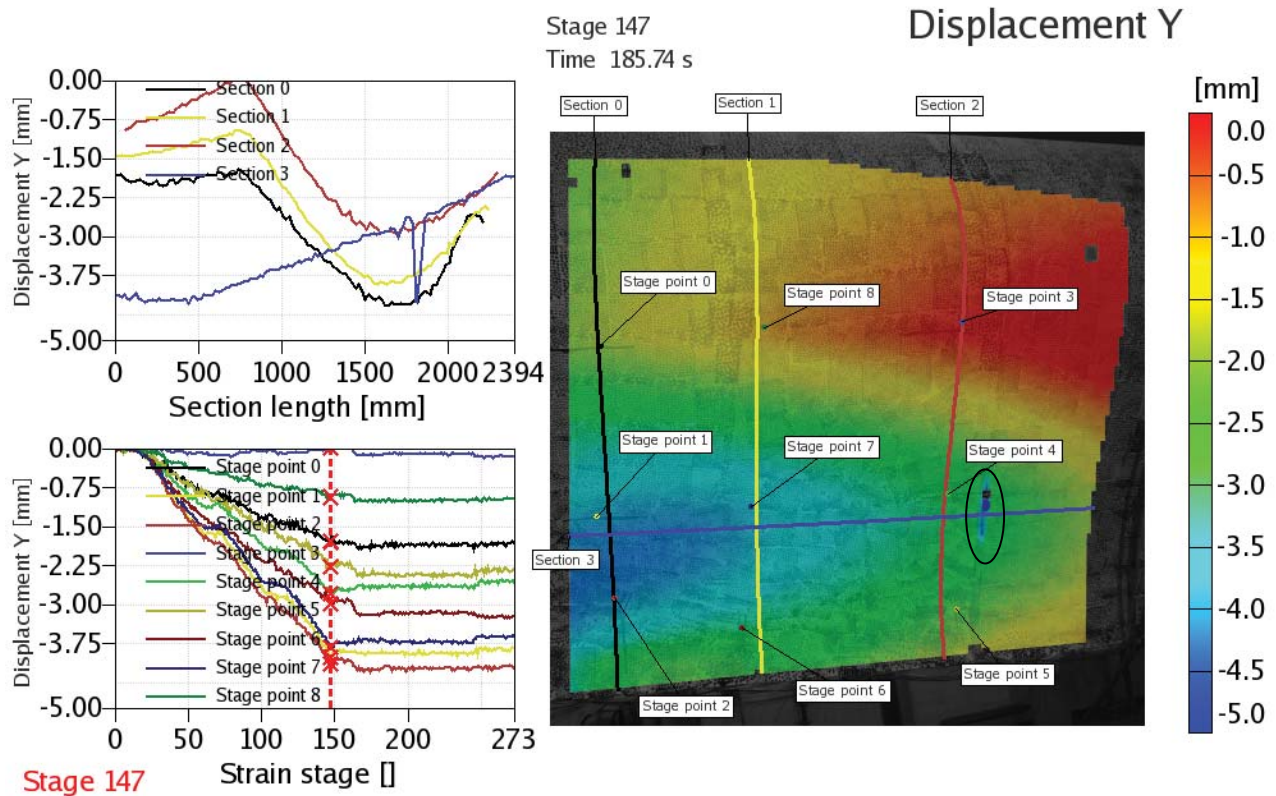


Test: ELTT_6_250610_C

The measurement was started at 12.5% load.

The maximum load during this test was 80%.

The DIC - measurement was conducted in the 11.5 meter region on the pressure side of the blade, see snapshot below



This measurement was performed because the strain gauge measurements at the trailing edge showed maximum values in this area.

The DIC measurement does not show anything peculiar. The blue to the right (circled) shows strain gauge cables loosening from the blade surface.

Risø DTU is the National Laboratory for Sustainable Energy. Our research focuses on development of energy technologies and systems with minimal effect on climate, and contributes to innovation, education and policy. Risø has large experimental facilities and interdisciplinary research environments, and includes the national centre for nuclear technologies.

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